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TECHNICAL REPORT
FD-35

ULTRA-HIGH COMPRESSION OF DRIED FOODS

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FMC Corporation
Santa Clara, California

Contract No. DA 19-129-AMC-163 (N)

November 1965

U. S. Army Materiel Command
U. S. ARMY NATICK LABORATORIES
Natick, Massachusetts

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FOREWORD

Increasing significance is being attached to the need for decreasing the weight and volume of all operational rations. Particular attention is directed to a special food packet designed for the combat soldier who must carry on his person his entire food supply for extended periods. Modern dehydration procedures, such as freeze dryinging, have provided for the removal of excess weight from virtually all familiar foods but have not provided for a corresponding reduction in volume. Previous studies point to compression as a feasible means for attaining a significant volume concentration. These studies, however, have been restricted to relatively low compression pressures. This investigation seeks to provide information on pressures substantially in excess of those heretofore applied to food. Observations are extended beyond a description of pressure-volume relationships to include physical, chemical, and organoleptic changes induced by such compression. These observations are intended to provide an insight into the advantages and disadvantages of compression at high pressures and to assess the feasibility of exploiting advantages in the design of components for special food packets.

This investigation was conducted in the Central Engineering Laboratories of the FMC Corporation in Santa Clara, California under contract DA19-129-AMC-163 through funds allocated to the project titled: Combat Feeding Systems. Dr. R. A. Lampi served as Official Investigator. His collaborators were H. Takahashi, R. F. Battey, J. Lennon and S. Sierra. Project Officer for the U. S. Army Natick Laboratories was Dr. Maxwell C. Brockmann of the Animal Products Branch, Food Division. Alternate Project Officer was Dr. Karl Johnson of the Plant Products Branch, Food Division.

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ABSTRACT

This report covers the study of the effects of pressures as high as 120,000 psi on various dried foods. High compression did not produce any detectable chemical changes. Compressed foods became difficult to rehydrate and exhibited considerable fragmentation when hydrated. Temperature changes occuring during high compression operations were studied. The equipment used for achieving high pressures and the construction of the die are discussed.

I. INTRODUCTION

This is the final report of Phase I on the investigation of the ultra-high compression of dried foods performed under Quartermaster Corps Contract DA 19-129-AMC-163(N). The objectives of this contract were to observe the effects of compressing representative dried foods at pressures up to 120,000 psi and to identify and examine those effects which may be exploited in the development of novel components for specialized food packets.

This report covers the following three phases of work performed:

1. The design and development of the die and equipment.

2. The investigation of compression procedures.

3. The study of the effects of ultra-high compression on selected dehydrated foods.

II. DESIGN OF HIGH PRESSURE DIE AND PRESS

A. Design Criteria for Die

The first step involved in the ultra-high compression of foods was the design and construction of a suitable die. A review of literature dealing with both compression of dried foods and very high pressure techniques led to the following design criteria:

1. A cylinder and piston design appeared best to meet the requirements.

2. A close fit between the piston and cylinder is necessary to minimze extrusion of the dry food during compression. The use of any type of gasket was ruled out because occluded gases would be prevented from escaping during compression.

3. The cylindrical section of the die was to be designed as though any pressure generated within the die would be transmitted equally toward the walls of the cylinder by the sample under compression.

4. The weight of the die and cylinder from a practical point should be around 25 pounds for ease of handling.

B. Cylinder Design

The final design is shown schematically in Figure 1 and pictorially in Figure 2. The outer portion of the die consists of a double-walled cylinder four inches long made of a high strength steel (AISI 4340). The two cylinders were fabricated with a 0.0059 inch interference at the 2.400 inch diameter, and assembled by means of a shrink fit. The inner cylinder was hardened to 420 - 440 Brinell

to increase its yield strength to about 195,000 psi. The outer cylinder was hardened to 340 - 360 Brinell, to give a lesser strength than the inner cylinder but somewhat more toughness. After assembly the inner diameter was finished 1.1300 ± 0.0002 inches. This cylinder as constructed weighed 21.3 pounds.

The compound construction results in a higher pressure rating than a simple cylinder. The inner cylinder is under compressive forces when there is no internal pressure in the die. These forces must first be overcome before the inner wall is subjected to tensile stress, the ultimate cause of failure of a cylindrical die. Theoretically, this cylinder can withstand an internal pressure of 218,000 psi before any permanent deformation occurs.

C. Piston and Anvil

Again referring to Figures 1 and 2, the construction of the piston and anvil (or lower piston) may be seen. The shoulders on the leading edges of the piston and anvil are finished to ± 0.0002 inch, as is the cylinder bore, with a 0.001 inch clearance between cylinder and piston. The area of the piston face is one square inch. The piston is made of AISI 4340 steel, heat treated in the same manner as the inner cylinder. The maximum load the pistons can support without permanent deformation is about 195,000 pounds. It has been calculated that at 120,000 psi pressure in the die, the diameter of the piston expands elastically by 0.001 inch to touch the cylinder walls. The piston and anvil supports serve to distribute the load on the faces of the press over a wider area than that of the piston and anvil. The weight of the piston, anvil and support was 4.3 pounds.

D. Anvil for Temperature Measurement

An anvil and support designed to permit a thermocouple lead into the interior of the die was made and is shown in Figure 3. This anvil is the same as the one described above except a hole is drilled vertically through the anvil and a slot along the bottom. This slot aligns with a hole in the side of the support to provide access for the thermocouple lead. The vertical hole in the anvil is enlarged at the anvil face and the thermocouple lead is cast in place with a plug of Wood's metal (melting point about 160° F.). To adequately support the lead wires, the metal plug must completely fill the vertical hole and partically fill the horizontal slot in the anvil with no air space. This anvil and support are shown in the manual press.

E. Presses for Ultra Compression

A manually operated and a motorized press were used to produce the ultra-high pressures. The manually operated press was constructed from 3/4" thick steel which had incorporated a hydraulic jack with a rated capacity of 100 tons. Figure 4 shows the die assembly with temperature measurement set-up in place in the manual press. The platform of the press was made from a solid piece of steel 10 x 14 x 5 inches weighing approximately 200 pounds. This heavy weight of the platform aided in the retraction of the hydraulic cylinder upon release of pressure. The motorized press used in some of the compression tests is shown in Figure 5 and the rated capacity of the machine was 120,000 psi.

III. FOODS USED IN THE STUDY

The twelve foods selected for the ultra compression studies are listed in Table 1. Only shrimp and chicken as purchased met the moisture specifications and all the other foods required further preparation to meet the specified moisture. Any freeze-drying that was needed was performed in FMC's pilot freeze-dryers and any further vacuum drying was carried out in a laboratory vacuum oven. The air-dried beef was first dried in a forced draft atmosphere oven at 100° F. for 16 hours followed by further drying at 105° F. in vacuum to bring the moisture below 2%.

IV. EXPERIMENTAL

A. Initial Compression Tests

The initial compression procedures served to evaluate the equipment performance and the techniques for ultra high compression. With the manual press, the most rapid and practical nip time (come-up time to pressure) was approximately 20 seconds, while on the motorized press both rapid (5 seconds) and regular (20 seconds) nip times were possible. Rapid compression on the motorized press did not allow for any dwell time because the pressure had to be released immediately to avoid damage to the machine. The manually-operated press was used for the bulk of the compression work because the operating conditions were more manageable and practical. The most practical operating condition of a 20 second nip time followed by a 10 second dwell time was decided upon as the standard ultra high compression procedure.

B. Performance of Die

The die and cylinder were checked for possible occluded gases in the compressed sample. A simple dial indicator was arranged to measure the movement of the work table relative to the top of the frame. (See Figure 6.) With this set-up it was possible to measure the density of a food while under compression within the die and compare this density with the food out of the die. The calculated density within the die was 1.6 - 1.7 gm/cc as compared to 1.1 - 1.4 gm/cc out of the die for apples, cabbage, shrimp and rice. Based on these comparisons there appeared to be very little occluded gases in the sample under compression.

When compressing chicken and beef some fat extrusion was encountered but was not considered a problem.

The anvil equipped with thermocouple leads functioned as expected in the measurement of the heat of compression except that the lead wires failed after six or so compression cycles. Repeated flexing of the wires before, during and after compression cycles was the chief reason for this failure and could not be avoided. By connecting the thermocouple leads to a recording thermometer it was possible to record the rapid temperature changes occurring during a compression cycle.

C. Density Measurements of Compressed Foods

After the initial tests to evaluate performance of the die and press, the first series of studies involved measurement of densities of the twelve foods compressed at three pressure levels. The densities of the compressed food were calculated by compressing a weighed amount of food and measuring the discs immediately upon removal from the die. The results of the density measurements are summarized in Table 2 along with the calculated reduction in volume. Increasing the compression level from 7,500 to 30,000 psi resulted in an appreciable (about 20%) volume reduction for most foods, but further increase in pressure to 120,000 psi resulted in a relatively small volume reduction.

Using the dial gauge, density measurements of shrimp and apples were calculated while under pressure in the die. From the data shown in Table 3 there is relatively little density change above 40,000 psi.

Most foods after compression resulted in smooth round disks except for apples and raisins. The thickness of these two foods would vary as much as 1/16-inch out of a nominal 1/4-inch upon removal from the die. Moreover, a check of the disk dimension of these two foods after several hours out of the die revealed varying degrees of density decreases indicating elastic behavior of these two foods.

The elastic behavior of the compressed foods at 120,000 psi were checked by using the dial indicator (see Figure 6). With this set up, it was possible to make thickness measurements of the food while under compression in the die. Food samples were compressed to 120,000 psi and released for several cycles while measurements were taken at intermediate pressures. These results showed good reproducibility, indicating that the food behaved elastically after the initial compression and that very little air remained trapped in the food while under pressure.

The elastic behavior of ultra compressed foods out of the die was checked with two foods. Density measurements of several compressed peas and beef were taken after various time intervals and the results are shown in Figures 7 and 8. Both foods show rapid losses in density up to 6 hours. The equilibrium density of beef appears to be independent of operating variables, whereas with peas density is a function of compression levels.

V. CHEMICAL ANALYSES OF COMPRESSED FOODS

A series of chemical tests were performed on the compressed foods to determine the effects of ultra-high pressures on food constituents. Three groups of tests were run to give information on protein, lipid and sugar on the uncompressed and compressed products. In all cases the emphasis is on any difference between compressed and uncompressed products rather than the absolute values.

A. Proteins

The primary effect to be expected by compression on the protein content of the

food is denaturation. Hamann (1) noted that egg white and whole blood serum are completely coagulated when compressed at pressures in the range of 90,000 to 110,000 psi for a period of several minutes to a half hour. Based on this information, samples of beef, chicken, shrimp and cod were analyzed before and after compression. The method used for detecting denaturation was based on solubility of proteins in an appropriate buffer solution and that the natural protein would be soluble while denatured protein would not.

A total nip, dwell and clear time of 30 seconds was followed in compression of the various samples for analysis, for it was felt that these conditions would more nearly represent practical commercial operations.

The analytical procedure was based on the method of Dyer, French and Snow (2) and was as follows:

A weighed amount of sample (compressed or uncompressed) was extracted with the appropriate buffer solution in a Waring blender for a total time of 1-1/2 minutes. Foaming and consequent protein denaturation during blending was minimized by using a metal plate which loosely fitted the jar below the surface of the liquid. This suppressed foam formation by reducing incorporation of air into the vortex of the swirling liquid. The temperature was kept below 5° C. by cooling the extraction solution in a freezer until ice crystals began to form. The blended sample was centrifuged for 10 minutes at 2,000 RPM and the clear liquid poured into the sample collection bottle. Additional buffer was added to the solid material remaining in the centrifuge bottle and the contents mixed with a stirring rod. After centrifuging again, the wash liquid was added to the original liquid to form the total extract of the sample. The protein contents of these extracts and also the original, dry sample were measured by the Kjeldahl method. The soluble protein in the extract and the total protein in the original sample was determined for compressed and uncompressed cod, shrimp, chicken and beef.

The results of the soluble protein analyses are summarized and shown in Table 4.

Some denaturation of shrimp was noted at 120,000 psi while changes in cod and cooked beef were insignificant. Much larger changes as a result of cooking are evidenced by the raw and cooked items tested, especially beef. (The same large batch of beef was used to prepare the raw and cooked freeze-dried product.) For the most part, the overall effect of pressure on proteins appears to be minor at the conditions investigated.

B. Lipids

A possible source of off flavors and odors in compressed foods are changes in lipids brought about by high pressures and the possible high temperatures during compression. Accordingly, several foods were examined for changes in total lipids extracted, peroxide number and free fatty acid content as a result of compression at 120,000 psi in 1/4-inch thick disks.

Slight differences in the amount of lipids extracted by chloroform were evident as shown in Table 5. The increases on compression are probably due to rupturing of tissue and subsequent increased extraction by the solvent. Chicken was the only food showing less lipid extracted on the compressed sample; this is no

doubt due to a slight extrusion of fat during compression.

The peroxide numbers of the lipids extracted from several foods are shown in Table 6. In the analysis Standby's (3) modification of Wheeler's (4) method was used. The results show no significant changes before and after compression.

The free fatty acid content of the extracted lipids for several foods was determined (5) with the results shown in Table 7. Most foods (cod excepted) showed slight decreases in free fatty acid content on compression, however the changes are not considered significant, with the possible exception of chicken. No explanation is offered for the reduction from 7.0 to 5.2% free fatty acid content for the chicken sample.

Based on the results from the lipid analysis, the indications are that no immediate detectable degration takes place.

C. Sugars

Several foods were selected for testing total and reducing sugars before and after compression. The data summarized in Table 8 showed no significant changes in total and reducing sugars before and after compression.

VI. REHYDRATION

Preliminary attempts to analyze rehydration of ultra-compressed foods revealed a need for a practical and somewhat uniform method to effect and quantify rehydration. Initial rehydration trials indicated that some agitation is required if rehydration in most foods was to take place in a practical With some foods it was difficult to distinguish between separation and actual rehydration, since the compressed disk fragmented rapidly but absorbed water slowly.

To minimize variable factors affecting rehydration, the following practical procedure was evolved.

1. Five 1/4-inch disks of one food were placed one each into five 250 ml wide-mouth flasks containing 100 ml of 160° F. water.

2. Each flask was then immersed in a 160° F. water bath. The neck of the flask was attached to a Burrel wrist action shaker which supplied a constant gentle agitation.

3. At the various selected intervals, one sample was removed and analyzed for the volume rehydrated or unhydrated by caliper measurements.

The set-up of the equipment is shown in Figure 9 and the results of the rehydration determinations are shown in Table 9.

From the results it can be observed that ultra compression affects the rehydration of some foods very markedly. Both milk and cod rehydrate rapidly in uncompressed

rm but become very difficult to hydrate after compression. On the other hand, chicken is relatively unaffected by compression. It is interesting to note when comparing the three differently dried beef samples that there exists marked differences in the respective rehydration rate and manner of rehydration. Product processing variables in this instance had a significant effect on rehydration.

VII. THE EFFECT OF SEVERAL VARIABLES ON REHYDRATION

Using the methods for the rehydration procedures previously described, several studies on the effect of variables on rehydration were carried out using compressed peas and rice. These two foods were selected for the tests because it was possible to produce uniform compressed disks and both rehydrated in an ideal manner and within a practical time of one hour. Product variables were achieved by adjusting the moisture content to two different levels prior to compression, and the compression variables involved were two operating temperatures. (The food and die were placed in an air oven several hours to attain the elevated operating temperature.)

Figure 10 shows the effect of operating temperature and moisture content on the rate of rehydration. Results with peas show that the rate of rehydration is directly proportional to operating temperature and moisture content.

Figure 11 shows both the effect of compression level and moisture content on rehydration rate. The compression level affected not only rate of rehydration but also the percent of final rehydration.

To check the effect of various disk thickness on rehydration, 1/16, 1/8 and 1/4-inch thick rice disks were prepared and rehydrated. The data plotted in Figure 12 shows that rehydration rate is inversely proportional to the thickness.

The effect of temperature and pressure is plotted on Figure 13. With rice, the rate of rehydration is a function of compression level and independent of operating temperature.

VIII. FRAGMENTATION

With the exception of milk, raisins and apples, all ultra-compressed foods exhibited various degrees of fragmentation due to pressure. Several foods were compressed to 1/4" thickness under 120,000 psi and were carefully rehydrated to show the effects of pressure on fragmentation. The rehydrated foods were then filtered through a Buchner funnel and photographed. Figures 14 through 19 show the effects of increasing pressure with an uncompressed control for comparison.

A. Rice, Figure 14

The samples were broken with a spatula to hasten the complete rehydration. All three compressed samples show fragmentation. The 120,000 psi sample when filtered formed a cake of very fine particles. Some swelling resulted from the half-hour exposure to 160° F. water.

B. Peas, Figure 15

The samples separated during rehydration within ten minutes and showed severe fragmentation.

C. Chicken, Figure 16

The 7,500 psi sample showed more fragmentation than those at higher pressure; this was confirmed by duplication. Possibly some fragmentation occurs at lower pressures but at higher pressure the food is pressed together to such an extent that no separation takes place on rehydration.

D. Cabbage, Figure 17

Breakage is evident here for all compressed samples. The samples at 30,000 and 120,000 psi required about thirty minutes to rehydrate (with some help by breaking with spatula) and had lost a large amount of their original green color.

E. Shrimp, Figure 18

The uncompressed shrimp was broken into pieces about 1/2 to 3/4-inch long to facilitate weighing the amount required for a 1/4" thick disk. Rehydration of the 30,000 and 120,000 psi samples was aided by breaking up the disk after about ten minutes' time. The fragmentation is evident in the photograph.

F. Raw, Freeze-Dried Beef, Figure 19

The picture shows some fine material in compressed samples but this may have been produced largely by stirring during rehydration. Samples of beef, if allowed to rehydrate undisturbed, will retain the disk shape but require more than an hour for a 1/4" disk.

IX. EFFECT OF VARIABLES ON FRAGMENTATION

The usual methods to quantify fragmentation are complicated by the long rehydration time and the agitation that is required. Moreover, the original food condition, the manner of rehydration, and the degree of rehydration precluded experimentation with many foods. Cabbage and beef samples were fairly well fragmented before compression, while cod and shrimp required fragmentation to smaller pieces to fit the die. Chicken and apples rehydrated

in a manner that fragmentation could not be compared.

Because of uniformity of sample and rehydration characteristics, dehydrated peas and rice were selected to evaluate the effect of variables on fragmentation.

Peas and rice equilibrated at two moisture levels were used to study the effect of product variables on fragmentation. Room temperature compression was compared with a sample compressed at an elevated temperature to evaluate the effect of an operating variable.

These compressed foods were all rehydrated in 160° F. water using the Burrell wrist action shaker. To achieve complete rehydration prior to filtration and photography, it was necessary to gently break apart some unrehydrated pieces with a spatula.

The results shown in Figures 20 and 21 show that more fragmentation occurred at the lower moisture content and operating temperature. It would appear than that fragmentation can be reduced either by elevating operating temperature or the moisture content of the food.

X. COMPRESSION TEMPERATURE MEASUREMENTS

Included in the studies on the ultra compression of foods was a study of temperature changes occurring within the various foods while under compression. Using the thermocouple-equipped anvil with the lead wires connected to a recording thermometer, it was possible to follow the temperature transitions occurring at each state of the compression cycle. The data gathered in the compression temperature measurements are shown in graphical form to show the relationships of pressure, time and the temperature of food during the compression cycle. Both the manually operated press and the motorized press were employed.

Figures 22 through 24 show changes in temperature occurring during the compression cycle with nine foods. In general, there is a rise of 10 to 20 °F. during compression and a corresponding cooling effect on pressure release. The greatest rise in temperature occurs at around 30,000 psi except for raisins, which showed a continued rise to 120,000 psi. Slightly higher compression temperatures were noted with milk.

A. Effects of processing variables on temperature

The compression temperatures of the three types of dried beef are shown in Figure 25. Since all three types of beef exhibited similar curves, process variables do not appear to influence compression temperatures.

B. Effect of lead placement on temperature measurement

To check reproducibility of the temperature measurements, three consecutive compressions were performed with raw freeze-dried beef. Operating variables such as lead placement in the compressed food, as well as sample variables, are not controllable. The results shown in Figure 26 indicate that with beef a spread of 7 degrees in maximum temperature was recorded. Similar tests with

other foods revealed that a spread of 10 degrees in maximum compression temperature can be expected.

C. Effect of moisture content on temperature

Two samples of beef and two samples of peas each at different moisture levels were compressed to determine if moisture variables affected compression temperature. Results shown in Figures 27 and 28 indicate that the effects of different moisture levels on compression temperature are insignificant.

D. Effect of thickness of disk on compression temperature

In Figure 28 the compression temperatures of two thicknesses of raw freeze-dried beef are plotted. Thicker disks appear to result in higher temperatures; on the other hand, the heat generated in the thinner disk appears to dissipate more quickly to the die. Since the heat loss to the die is uncontrollable, it is difficult to make an assessment of thickness effects on temperature.

E. Effect of initial operating temperature

To study the effects of initial operating temperatures on heat of compression, three compressions of dried beef were performed at three temperatures. The sample and die were first equilibrated to several temperatures and then compressed. Judging from the results shown in Figure 30, the initial operating temperature did not result in any significant changes in compression temperature differentials.

F. Effect of rapid come-up time on compression temperatures (Figures 31 - 34)

Ultra compressions on dried beef, cabbage, apple dices and milk were performed on the motorized press and on the manual press to study the effects of rapid come-up time on compression temperature. The nip time or come-up-to-pressure time with the motorized press was approximately 5 seconds, while with the manual press the nip time was 20 seconds. Only milk showed any significant increase in compression temperature resulting from rapid compressions. Judging from the results obtained, the use of rapid come-up time does not have any enhancing action on compression temperature.

G. Effect of gaseous environment on compression temperature

Several compression temperature measurements were performed in helium and in a mixture of 45-55 oxygen-nitrogen atmospheres. The die with the food inside was placed in a vacuum chamber and 29 inches of vacuum applied for 5 minutes. The vacuum was then broken by the introduction of one of the gas mixtures. After two such vacuum and gas release cycles, the die and food were quickly pressed to 120,000 psi. Judging from the results shown in Figures 35, 36, and 37, the use of helium and nitrogen-oxygen atmospheres did not affect the compression temperature.

XI. CONCLUSION

The objectives of this project were to investigate the effects of pressures up to 120,000 psi on various dried foods and to identify effects exploitable for

specialized food packets. This report covers the construction of dies and the equipment used for the ultra high compression of twelve dehydrated foods. Based on the results of the compression, the following observations can be made:

A. The ultra-high compression of dried food did not cause any detectable chemical changes. Samples checked before and after compression indicated that no significant deteriorative changes occurred from the effects of pressure up to 120,000 psi.

B. Most foods become difficult to rehydrate after ultra-high compression. Agitation, and in many cases fragmentation, is necessary to facilitate rehydration. In several foods, dried milk powder and cod, the compressed product became very nearly insoluble.

C. Ultra compression results in considerable fragmentation in most foods and the degree of fragmentation is proportional to the increase in pressure.

D. The greatest changes in density occur up to 30,000 psi; above this level density increases become negligible. Most foods after initial compression exhibit elastic behavior on subsequent pressure-release cycles.

E. A rise of 10 to 20 °F. was experienced for most foods undergoing compression, and a corresponding cooling effect on pressure release. Variations in nip time did not significantly affect compression temperatures. The greatest temperature increase was noted during come-up to 30,000 psi.

The post-compression stability of dried foods in terms of moisture sorption characteristics and chemical changes was not evaluated in this phase. If the foods were found to be stable, the exploitable results of ultra-high compression would be increased stability, increased caloric density and reduced protective packaging requirements. Specific novel uses, such as utilization for structural purposes, might then be realized.

XII. LITERATURE CITED

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APPENDIX

FOODS SELECTED FOR ULTRA-HIGH COMPRESSION STUDIES

TABLE 1

Food	Condition As Purchased	Original Moisture % Wt.	Preparation Required	Final Moisture % Wt.
Cod	Raw, frozen	-	Freeze-dry	0.6
Shrimp	Cooked, freeze-dried	1.9	None	1.9
Chicken	Cooked, freeze-dried	1.1	None	1.1
Beef	Raw	-	Freeze-dry	0.6
Beef	Raw	-	Cook, freeze-dry	0.3
Beef	Raw	-	Air-dry	1.2
Peas	Raw, frozen	-	Cook, freeze-dry	0.2
Cabbage	Air-dried	5.6	Vacuum-dry	1.8
Rice	Cooked, dried	9.8	Vacuum-dry	0.3
Non-fat milk	Air-dried	3.3	Vacuum-dry	1.2
Raisins	Air-dried	-	Vacuum-dry	3.4
Apples	Air-dried	-	Vacuum-dry	4.4

TABLE 2

DENSITIES OF COMPRESSED DRIED FOODS AND VOLUME REDUCTION
All measurements made on 1/4" thick disks out of die

Food	Density (gm/cc) at press (psi)			Reduction in volume %	
	7,500	30,000	120,000	7,500 → 30,000	30,000 → 120,000
Cod	0.84	1.09	1.12	23	3
Shrimp	0.80	1.05	1.07	24	2
Chicken	0.83	1.02	1.03	20	1
Beef - Raw Freeze-dried	0.89	1.02	1.02	13	0
Beef - Cooked Freeze-dried	0.90	1.06	1.07	15	1
Beef - Air-dried	0.96	1.08	1.11	13	2
Peas	0.82	1.13	1.25	27	10
Cabbage	1.02	1.32	1.41	23	6
Rice	--*	1.12	1.22	--	8
Non-fat dry milk	0.93	1.21	1.39	25	13
Raisins	1.37	1.42	1.44	4	1
Apples	--**	1.05	1.03	--	--

* No measurement possible - disk disintegrated upon removal from die
** Difficult to measure - top and bottom surfaces not flat

TABLE 3

PRESSURE - DENSITY DATA FOR DRIED FOODS (1)

Shrimp

Pressure, psi	Density, g/cc
0	1.45
40,000	1.61
80,000	1.67
120,000	1.70

Apples (Vacuum dried to 1.0% wt. moisture)

Pressure, psi	Density, g/cc
0	1.52
20,000	1.55
40,000	1.57
80,000	1.59
120,000	1.60

(1) Density of the food inside the die during compression.

TABLE 4

PROTEIN DENATURATION

Food	Soluble Protein, % of Total Protein	
	Uncompressed	Compressed
Cod, raw	27.4	25.1
Shrimp, cooked	18.4	13.0
Chicken, cooked	13.9	10.3
Beef, raw, freeze dried	35.4	30.8
Beef, cooked, freeze dried	13.7	13.4

Notes: (1) Protein analysis by the Kjeldahl method, exclusive of nitrate nitrogen.

(2) All foods were compressed at 120,000 psi in disks 1/4 inch thick.

(3) Cod and shrimp (about 5 gram sample) were extracted with 250 ml of a 5% NaCl, 0.02M $NaHC_3$ solution.

(4) Chicken (about 2.25 gram sample) was extracted with 250 ml of a 0.672M KCl, 0.065M H_3BO_3, 0.0013M $Na_2B_4O_7 \cdot 10H_2O$ solution.

(5) Beef (about 9 gram sample) was extracted with 250 ml of a 0.5M KCl, 0.03M $NaHCO_3$ solution.

(6) All extractions are carried out at temperatures in the 0 - 5°C range.

TABLE 5

PERCENT LIPIDS (1) EXTRACTED BY CHLOROFORM

Food	Uncompressed	Compressed (2)
Cod	1.0	1.7
Shrimp	2.9	3.3
Chicken	6.7	6.5
Cooked Beef	6.9	7.2

(1) As percent of original dry sample.

(2) At 120,000 psi, 1/4 inch thick.

TABLE 6

PEROXIDE NUMBERS (1)

Food	Uncompressed	Compressed (2)
Cod	>.1	>.1
Shrimp	>.1	>.1
Chicken	.877	.956
Cooked Beef	>.1	>.1

(1) Peroxide No. = millimoles peroxide per 1000 grams fat.

(2) At 120,000 psi, 1/4 inch thick.

TABLE 7

FREE FATTY ACID CONTENT (1)

Food	Uncompressed	Compressed (2)
Cod	61.8	56.8
Shrimp	13.58	13.05
Chicken	1.39	1.42
Raw Beef	7.2	6.7
Cooked Beef	3.18	2.9

(1) Results reported as percent oleic acid of the fat extracted from the original sample.

(2) At 120,000 psi, 1/4 inch thick.

TABLE 8

TOTAL AND REDUCING SUGARS (1)

Food	Total Sugar		Reducing Sugar	
	Uncompressed	Compressed(2)	Uncompressed	Compressed(2)
Peas	31	32	18	19
Cabbage	57	56	53	56
Non-fat milk	53	50	53	50
Raisins	87	88	78	81
Apples	85	84	70	70

(1) Results reported as per cent invert sugar in the original dry sample.

(2) At 120,000 psi, 1/4 inch thick.

TABLE 9

REHYDRATION OF COMPRESSED FOODS

All disks compressed to 1/4" thickness
Dwell time 20 seconds at 120,000 psi at room temperature

Food	Percent rehydrated at: (minutes) 5	10	15	30	60	
Beef - air-dried	99					Disintegrates on rehydration
Beef, cooked	29		53	98		Retains shape of disk with some delamination at rehydration
Beef, raw	24			47	66	Retains shape of disk at rehydration
Cabbage	11	24	38		77	Fragments on rehydration
Chicken	95	100				Separates rapidly
Cod	22	29	38		60	Slow to rehydrate and no separation on rehydration
Peas	24		27	57	100	Severe fragmentation
Rice	27		37	53	72	Disk fragments as rehydration progresses
Shrimp	19	1	60	100		Disk completely disintegrated
Apples						Disk fragments and subsequent water pick-up slow; no defined rehydration end point
Milk						Does not rehydrate within one hour even if fragmented by hand
Raisins						Separates rapidly but individual raisins slow to rehydrate

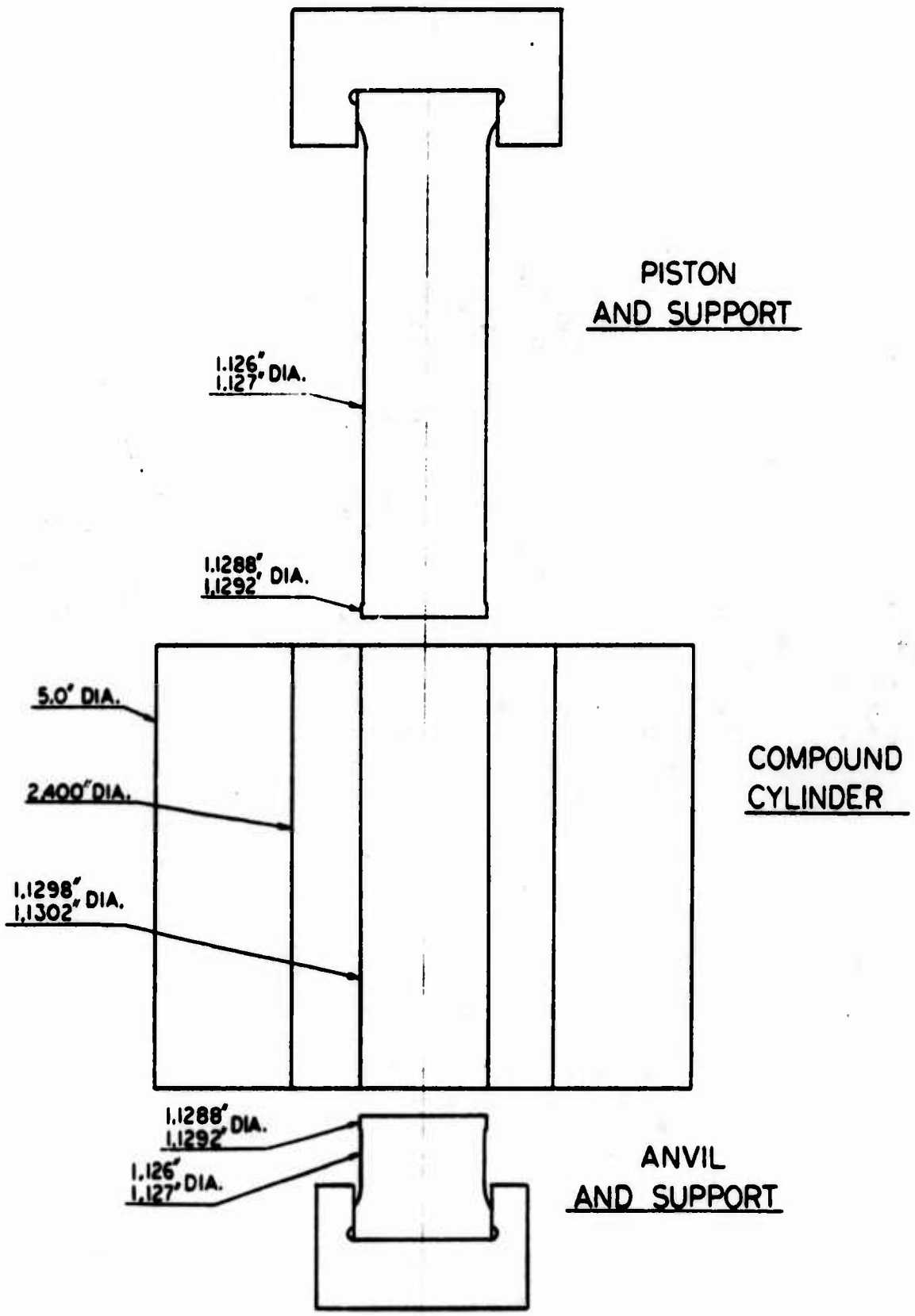


Figure 1 PISTON AND CYLINDER DIE CONSTRUCTION

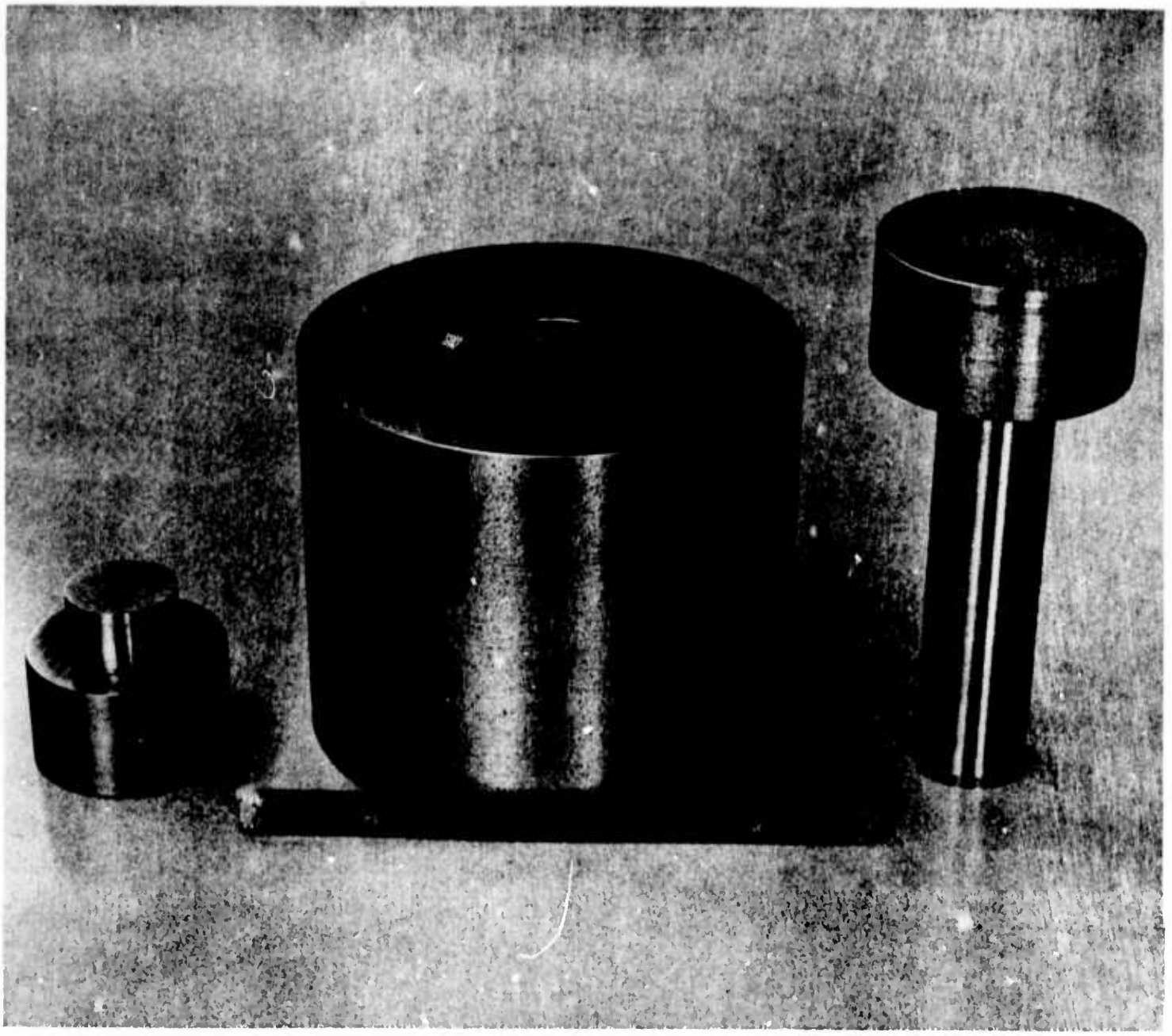


Figure 2 COMPLETED DIE

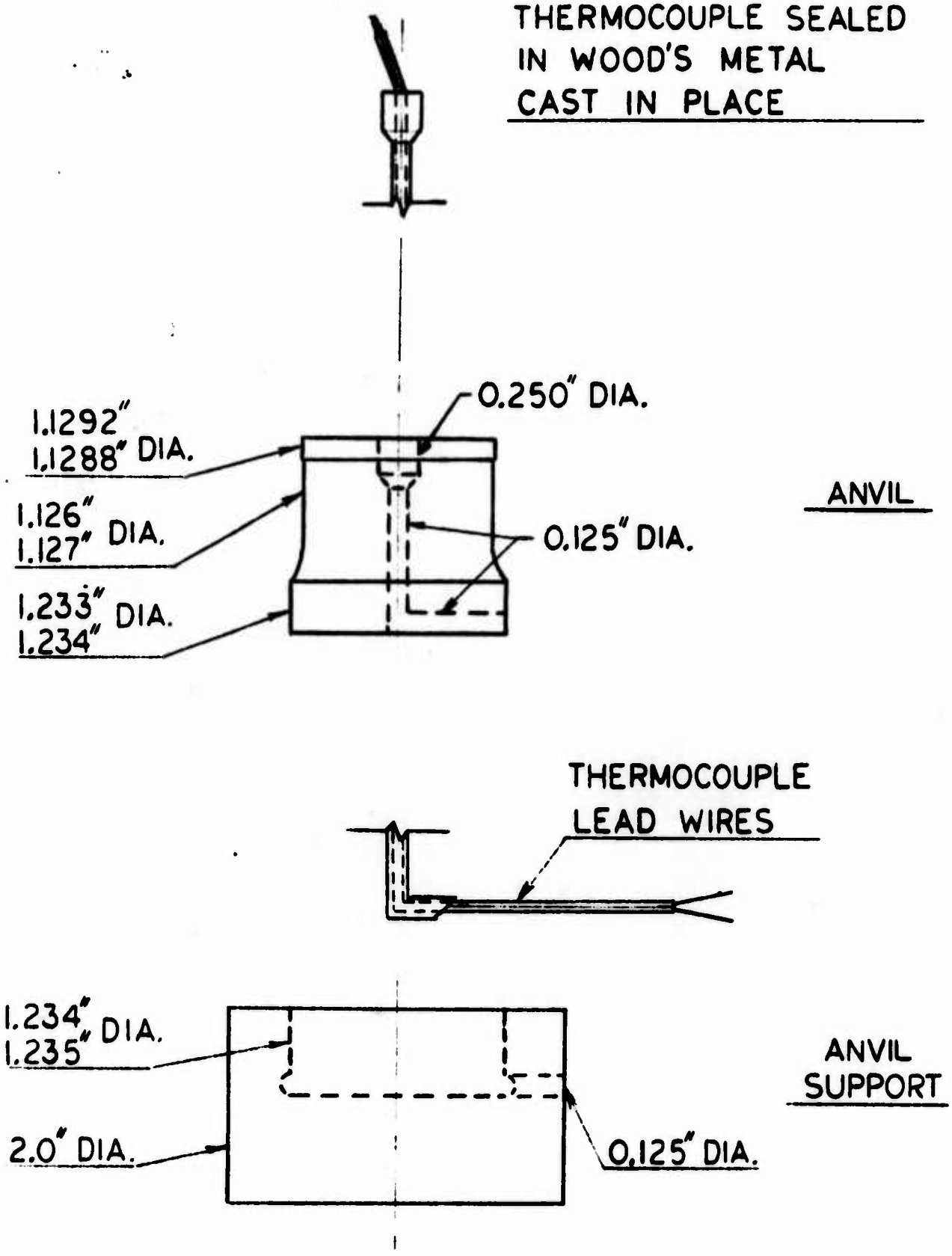


Figure 3 ANVIL DESIGN FOR TEMPERATURE MEASUREMENT

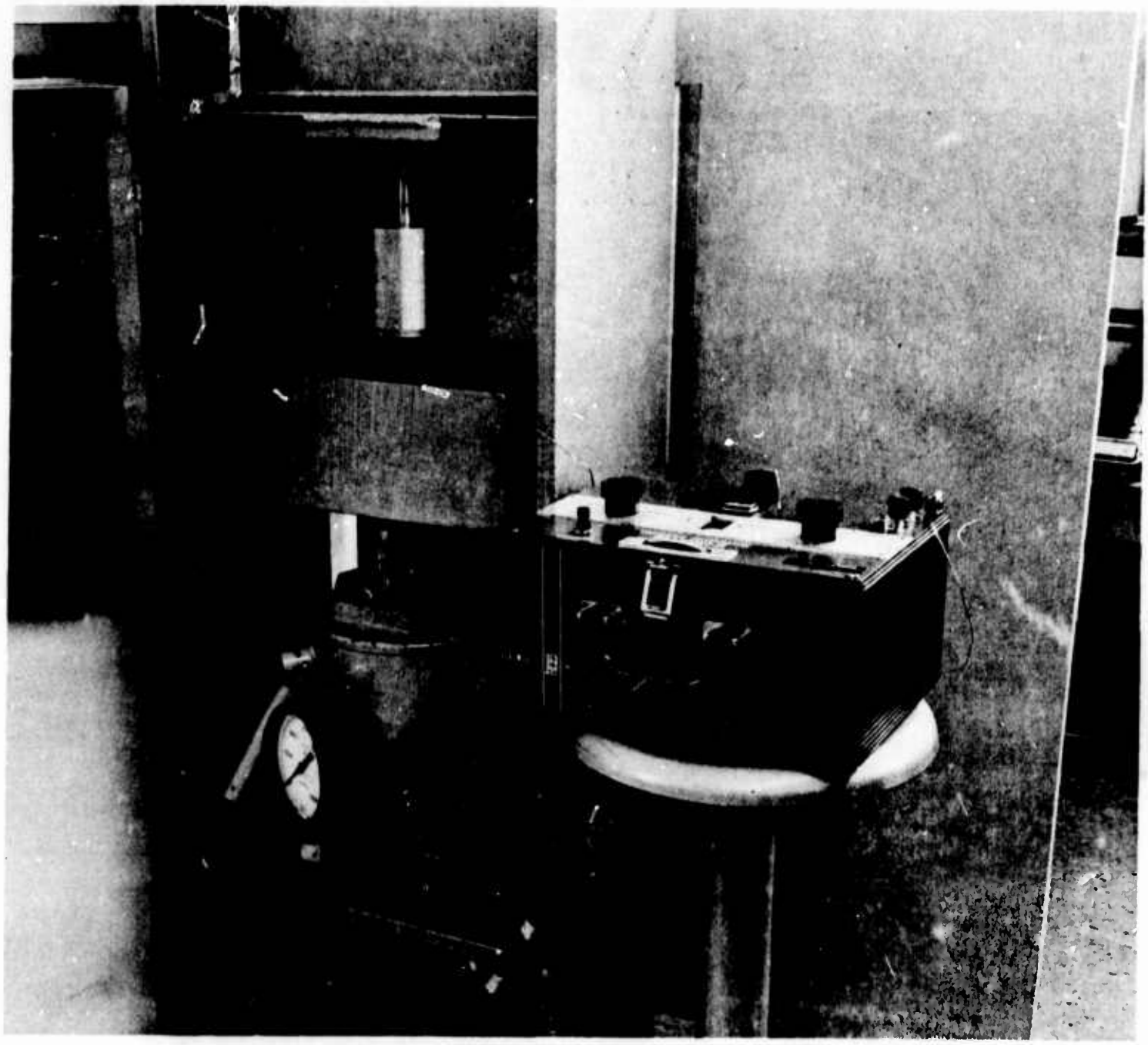


Figure 4 MANUAL PRESS WITH DIE SET UP FOR TEMPERATURE MEASUREMENT

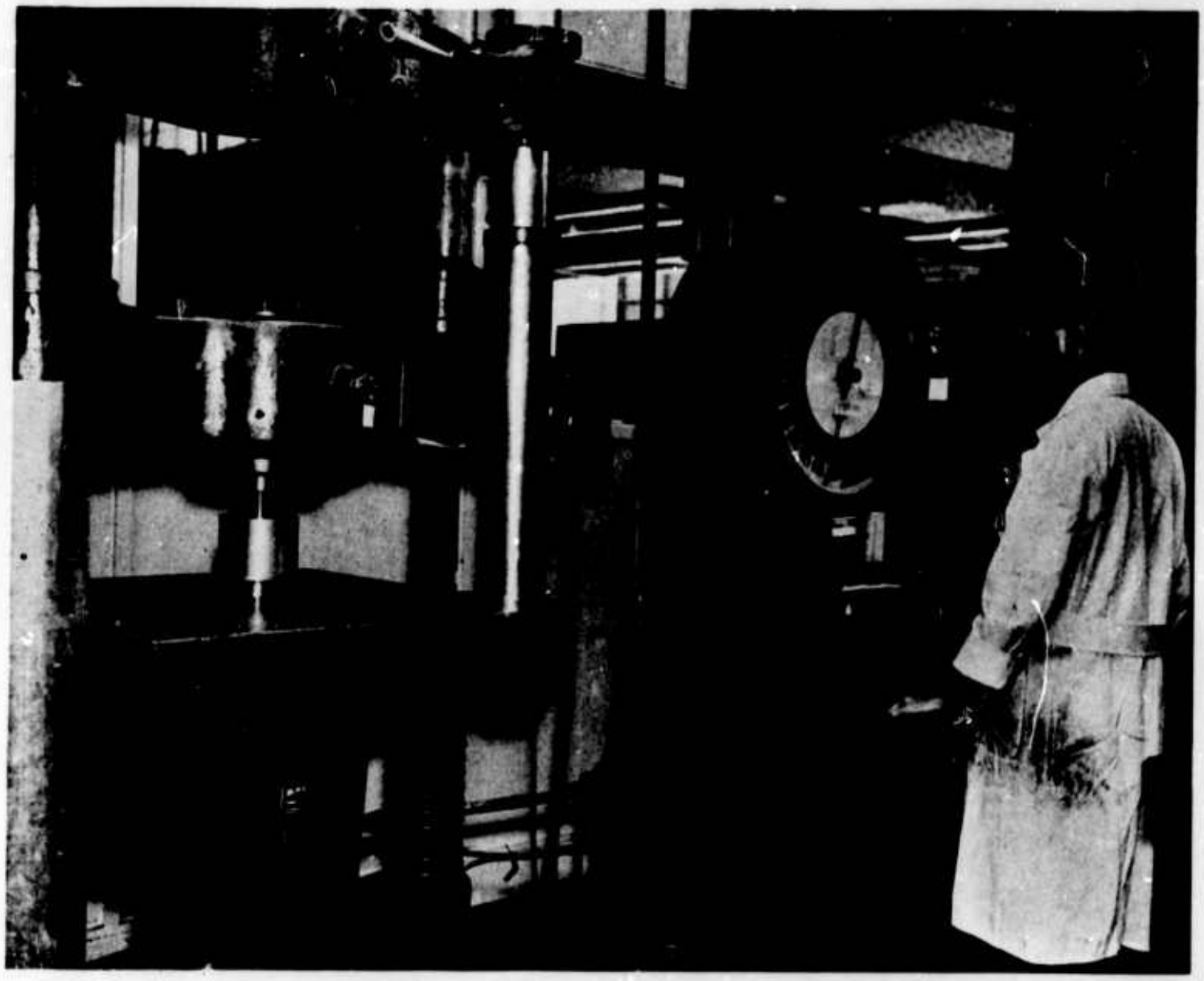


Figure 5 DIE IN POSITION IN 120,000 LB. TESTING MACHINE

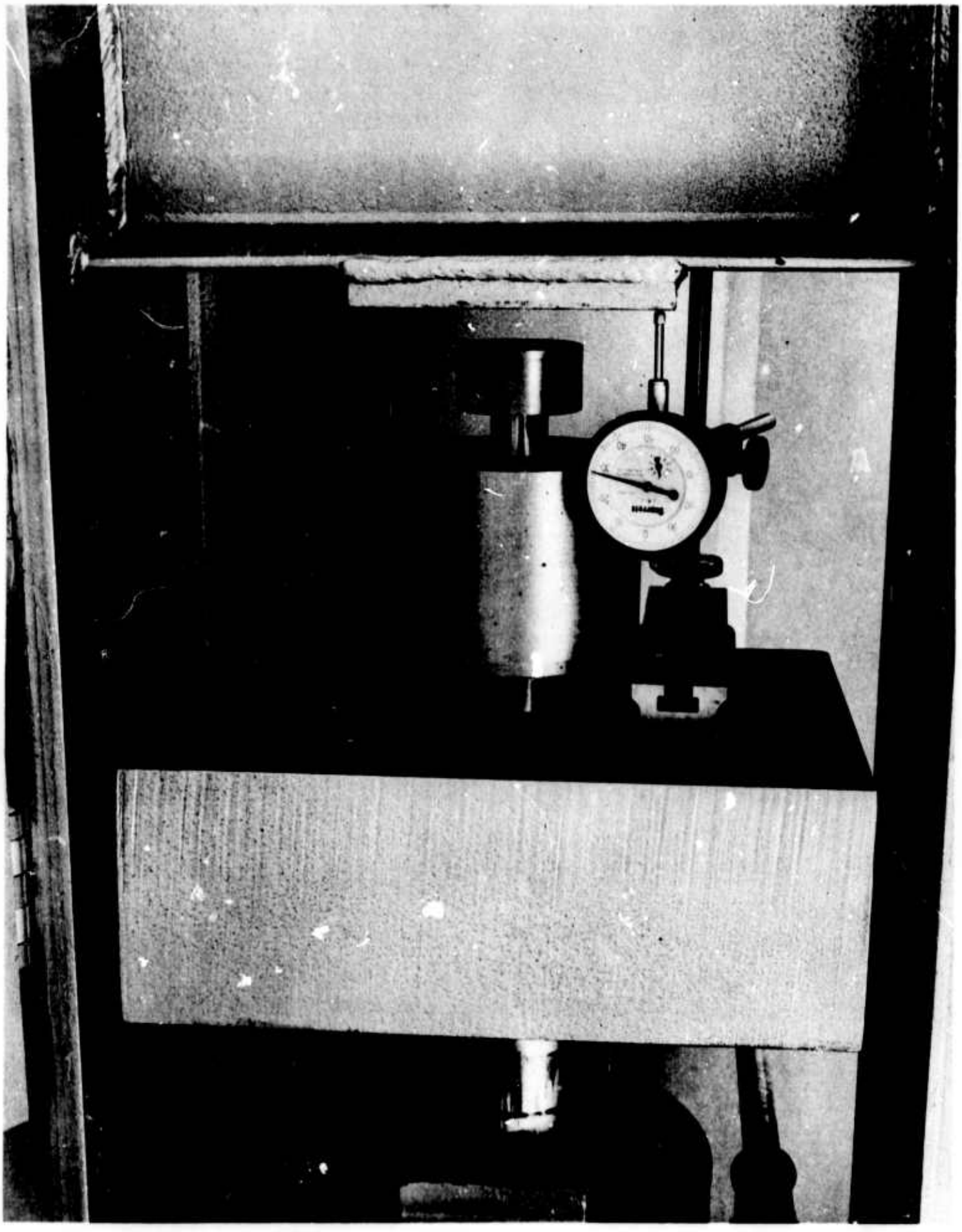
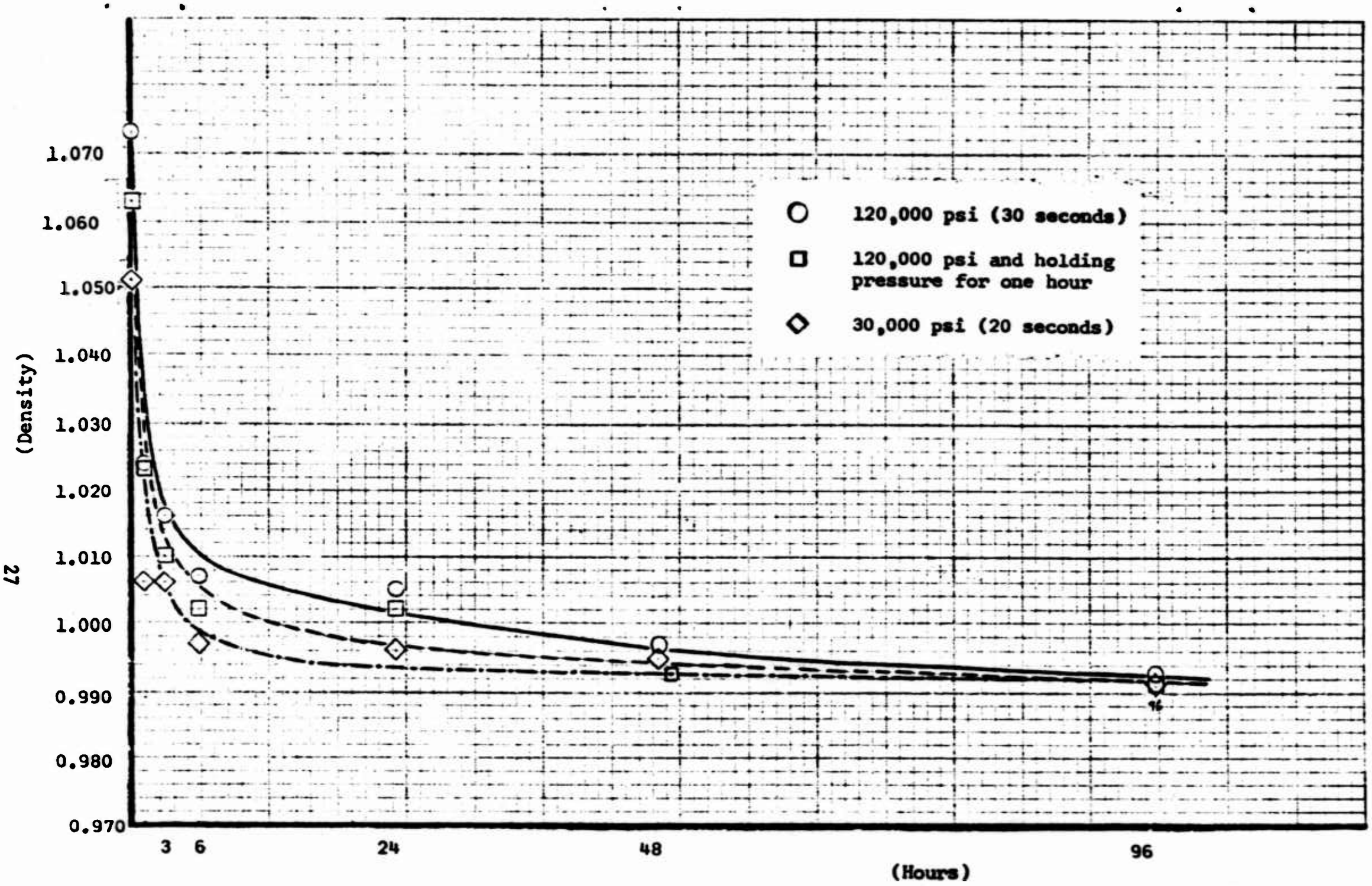


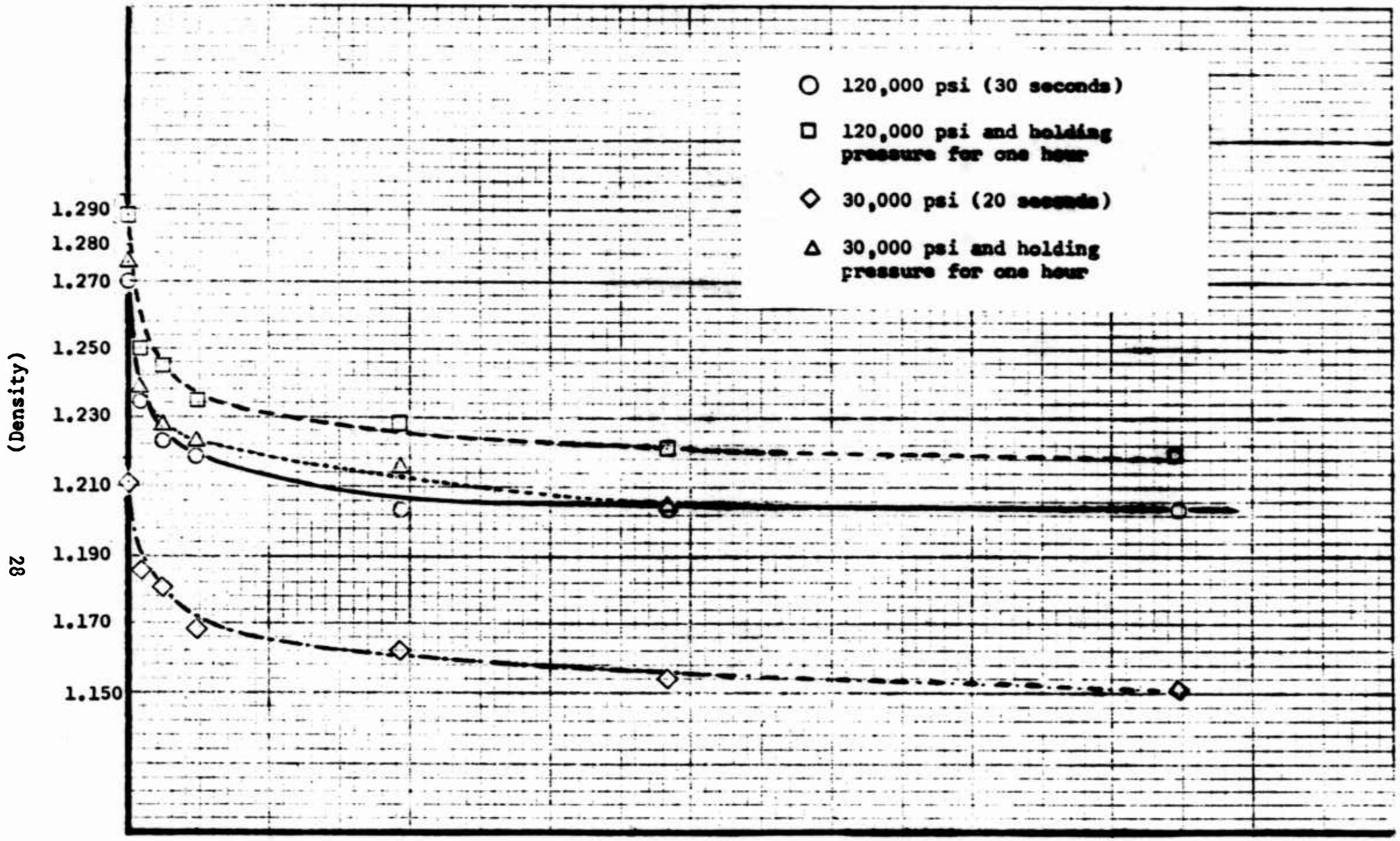
Figure 6 DIE IN MANUAL PRESS SET UP FOR DISPLACEMENT MEASUREMENT



Raw Freeze-Dried Beef (0.6% M.C.)

EFFECT OF DWELL TIME AND PRESSURE ON DENSITY

FIGURE 7



Peas (0.2% M.C.)

EFFECT OF DWELL TIME AND PRESSURE ON DENSITY

FIGURE 8

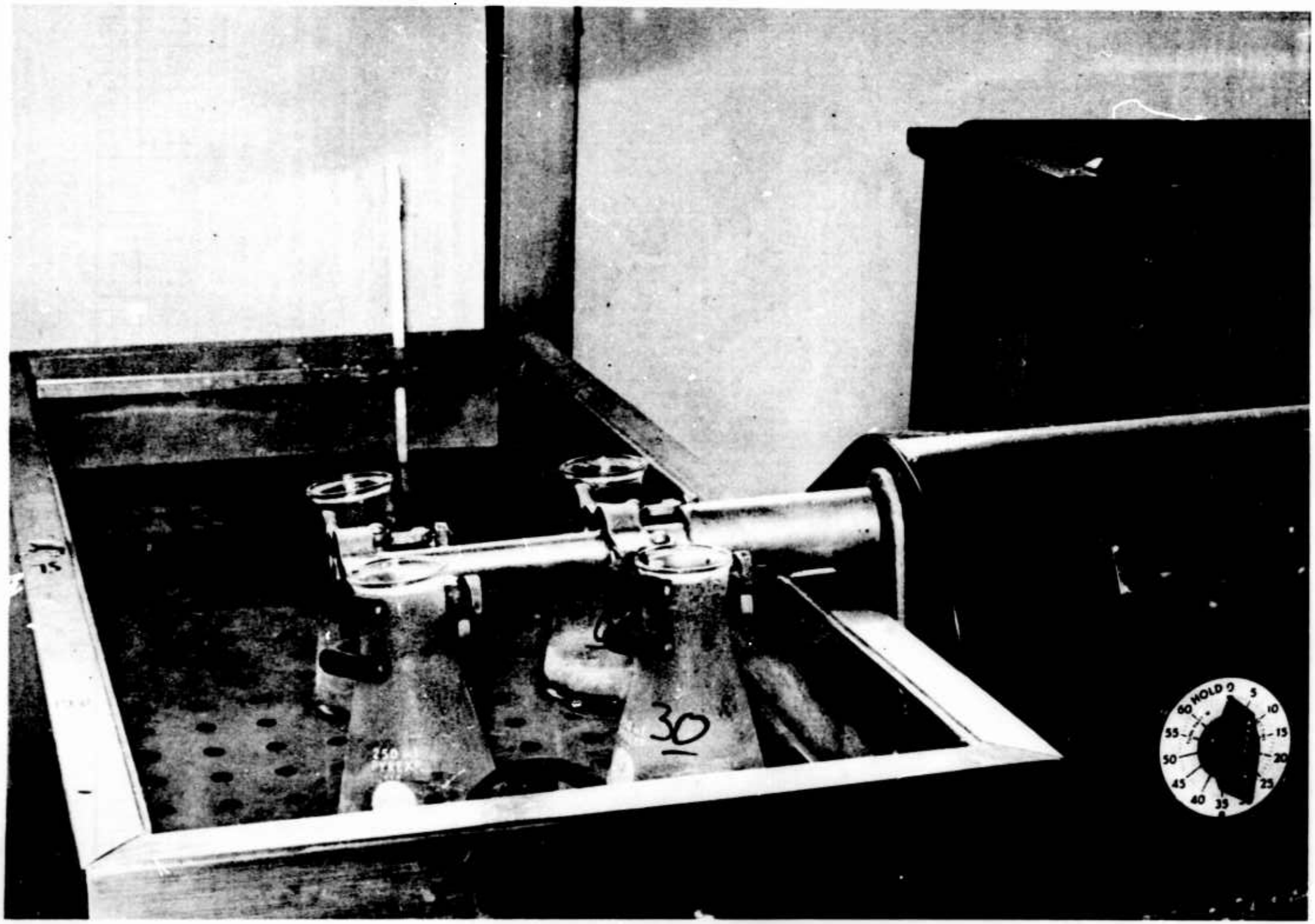


Figure 9 BURREL WRIST ACTION SHAKER

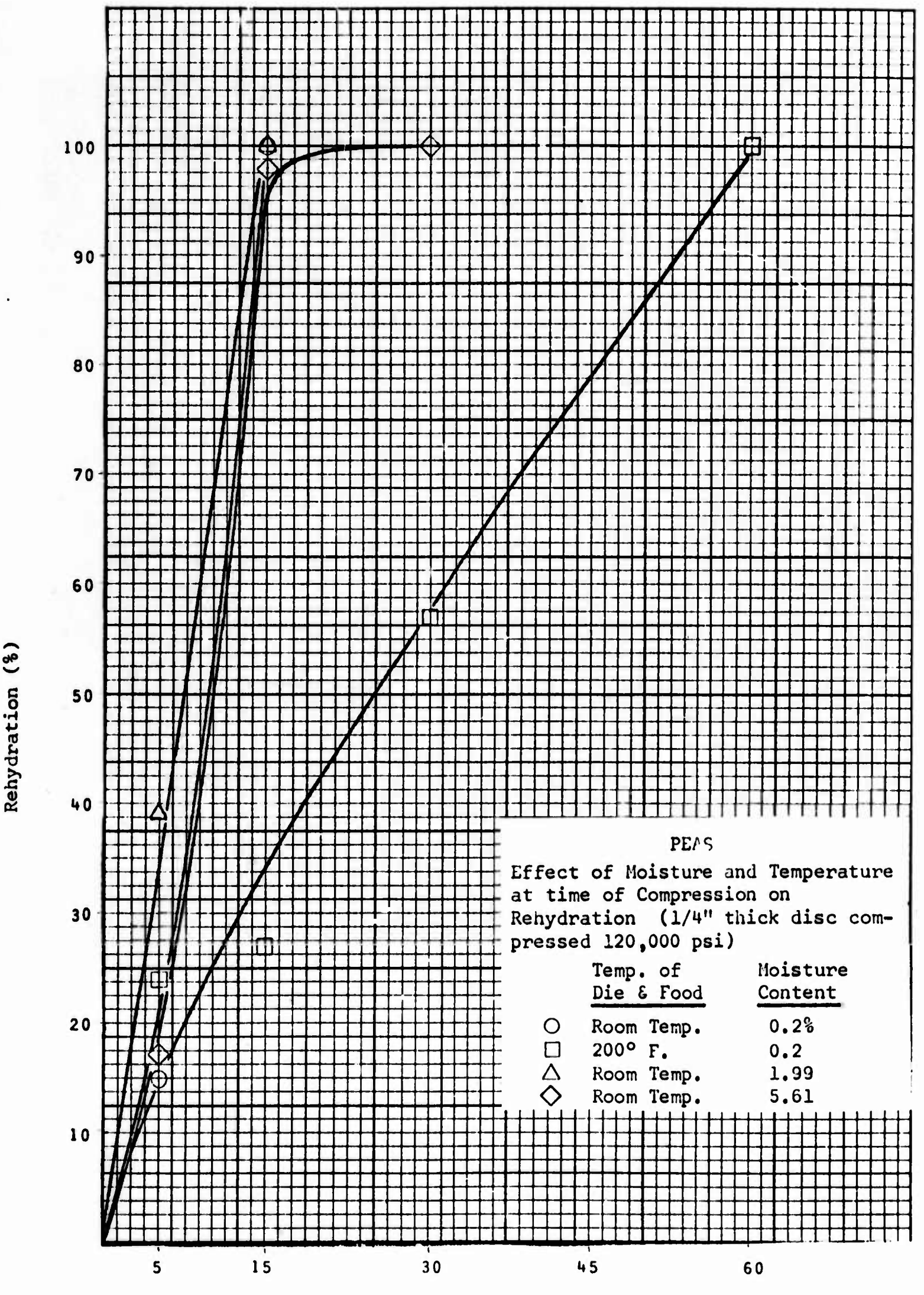

Rehydration (%)
100
90
80
70
60
50
40
30
20
10
5
15
30
45
60
Time (minutes)
PEAS
Effect of Moisture and Temperature at time of Compression on Rehydration (1/4" thick disc compressed 120,000 psi)
Temp. of Die & Food
Moisture Content
Room Temp. 0.2%
200° F. 0.2
Room Temp. 1.99
Room Temp. 5.61

FIGURE 10

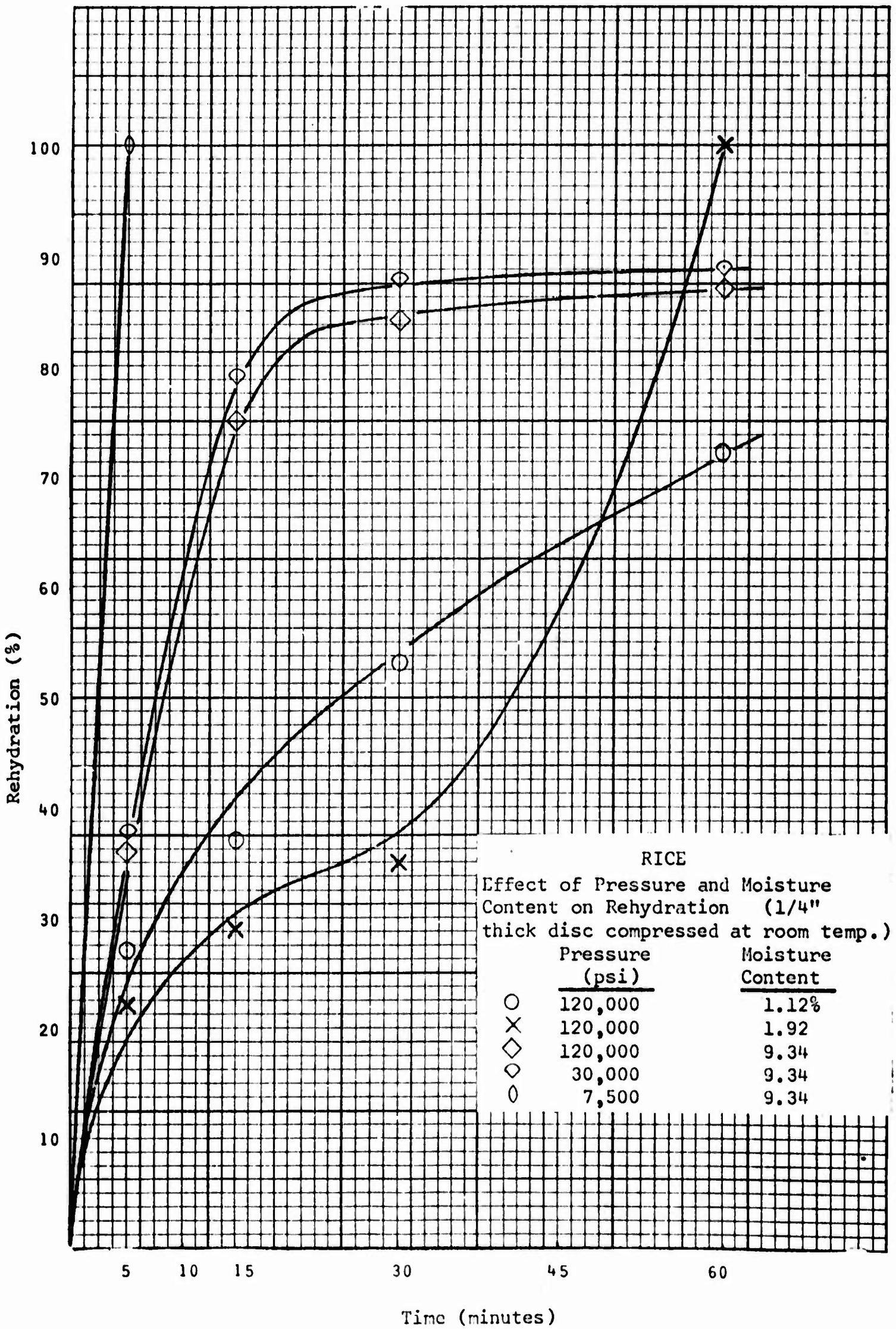

100
90
80
70
60
50
40
30
20
10
Rehydration (%)
5
10
15
30
45
60
Time (minutes)
RICE
Effect of Pressure and Moisture Content on Rehydration (1/4" thick disc compressed at room temp.)
Pressure (psi)
Moisture Content
120,000 1.12%
120,000 1.92
120,000 9.34
30,000 9.34
7,500 9.34

FIGURE 11

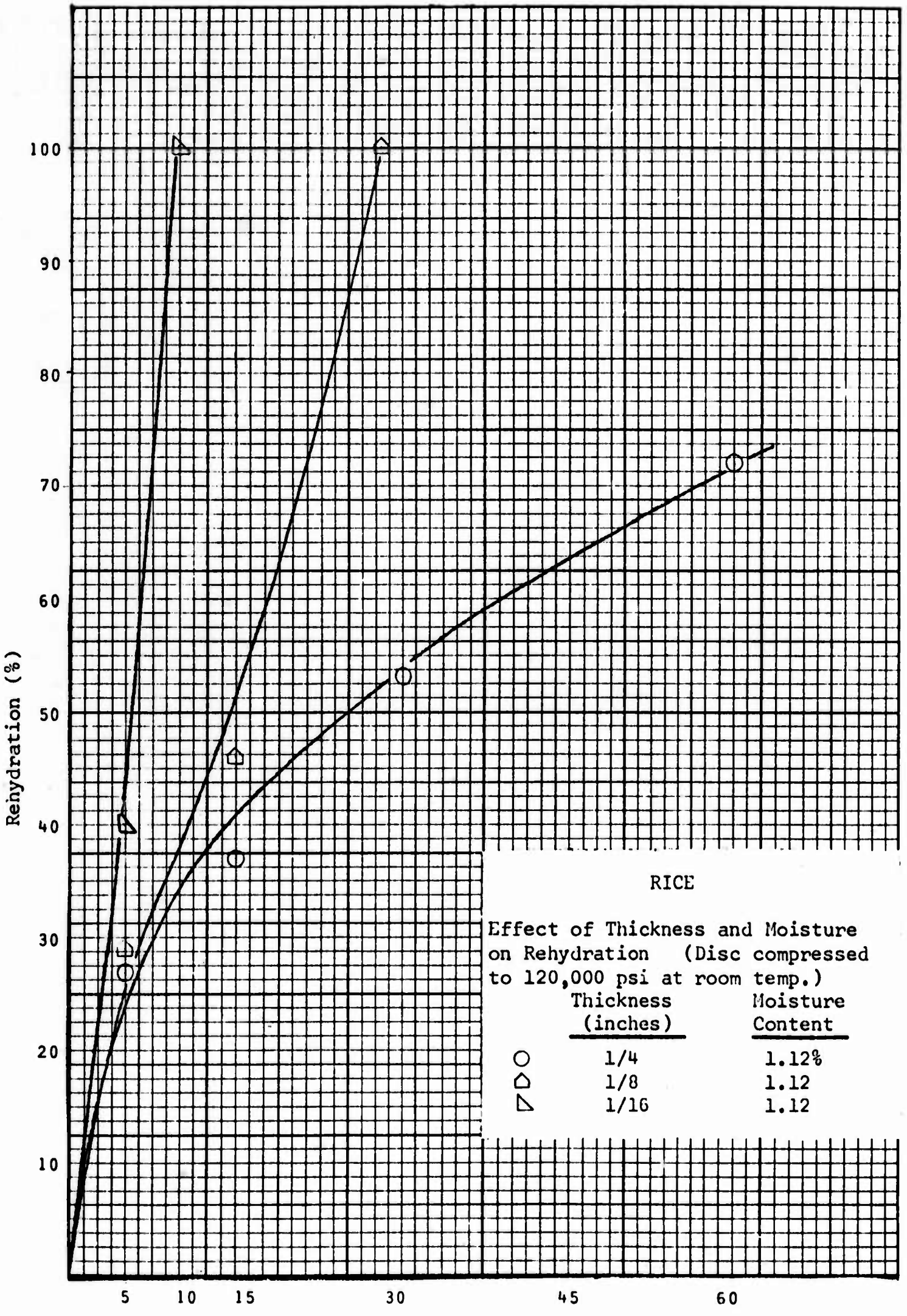

Rehydration (%)
100
90
80
70
60
50
40
30
20
10
5
10
15
30
45
60
Time (minutes)
RICE
Effect of Thickness and Moisture on Rehydration (Disc compressed to 120,000 psi at room temp.)
Thickness (inches)
Moisture Content
1/4
1.12%
1/8
1.12
1/16
1.12

FIGURE 12

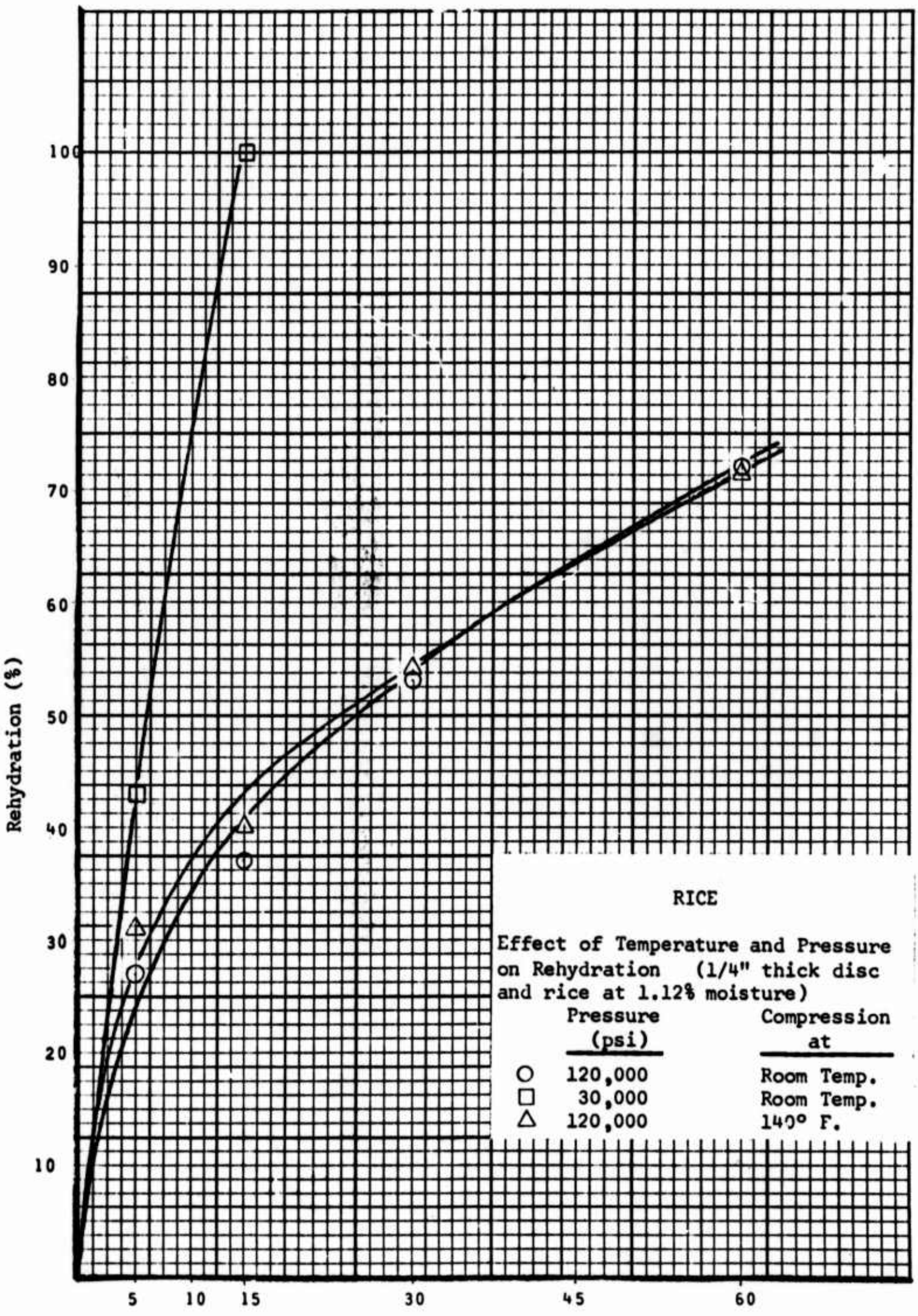

Rehydration (%)
100
90
80
70
60
50
40
30
20
10
5
10
15
30
45
60
Time (minutes)
RICE
Effect of Temperature and Pressure on Rehydration (1/4" thick disc and rice at 1.12% moisture)
Pressure (psi)
Compression at
○ 120,000 Room Temp.
□ 30,000 Room Temp.
△ 120,000 140° F.

FIGURE 13

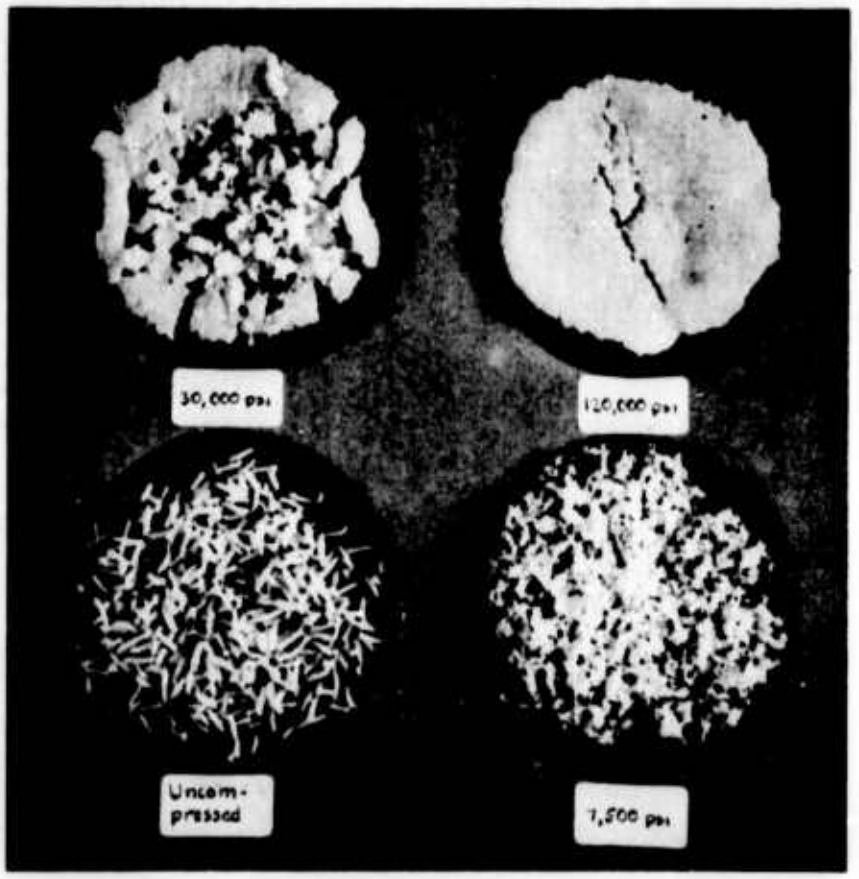


Figure 14 FRAGMENTATION OF RICE

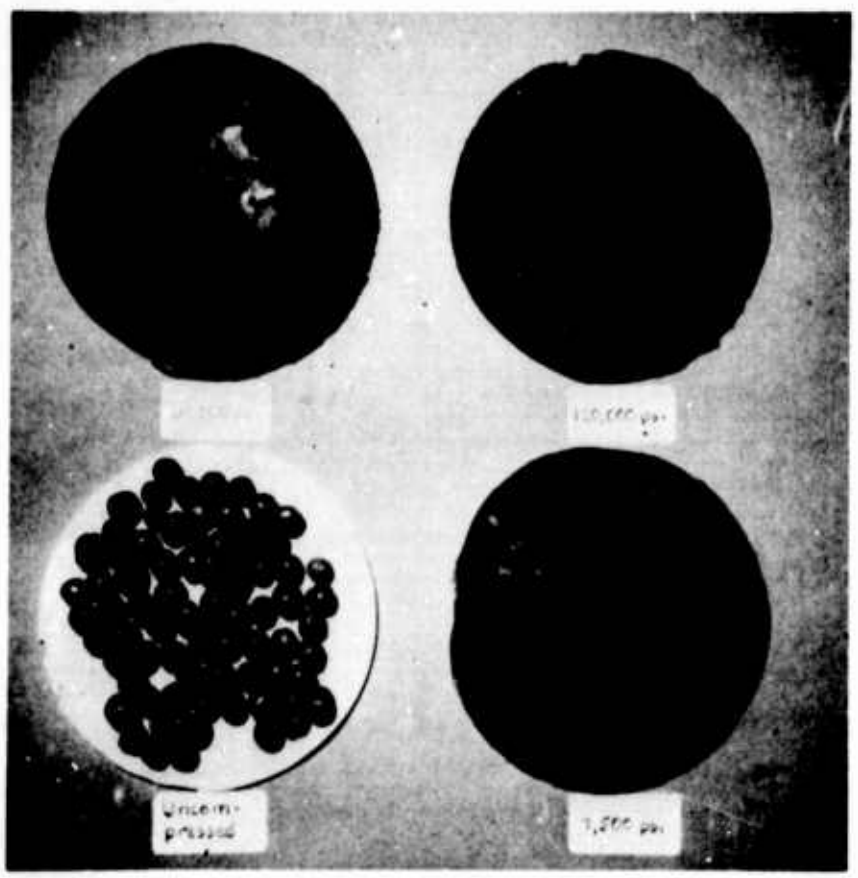


Figure 15 FRAGMENTATION OF PEAS

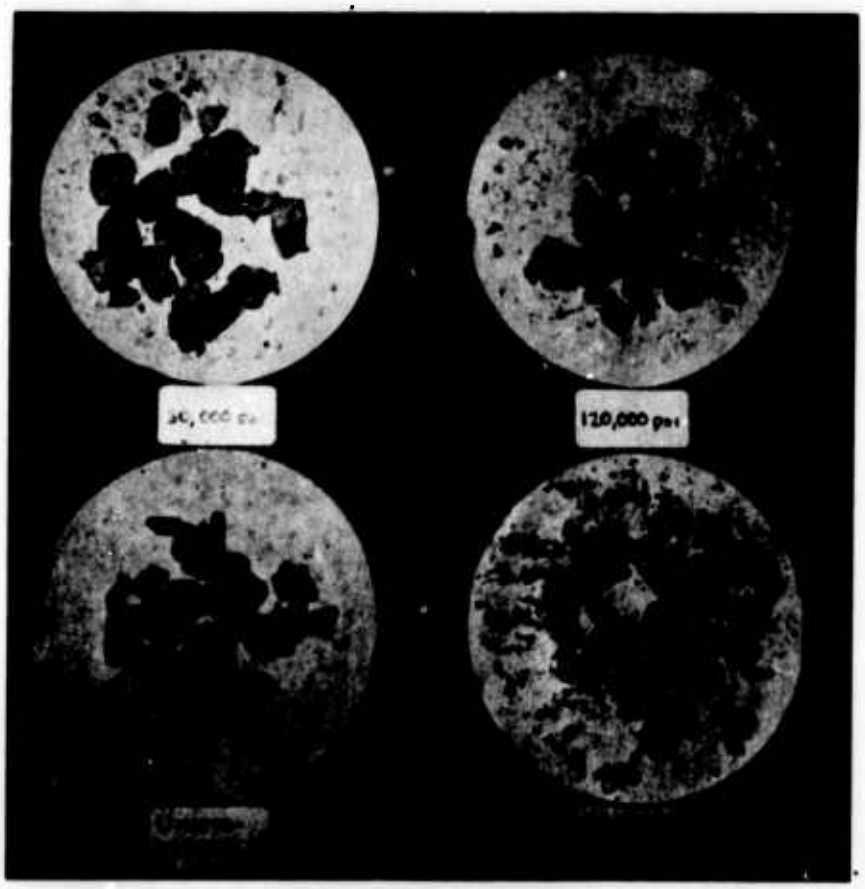


Figure 16 FRAGMENTATION OF CHICKEN

Figure 17 FRAGMENTATION OF CABBAGE

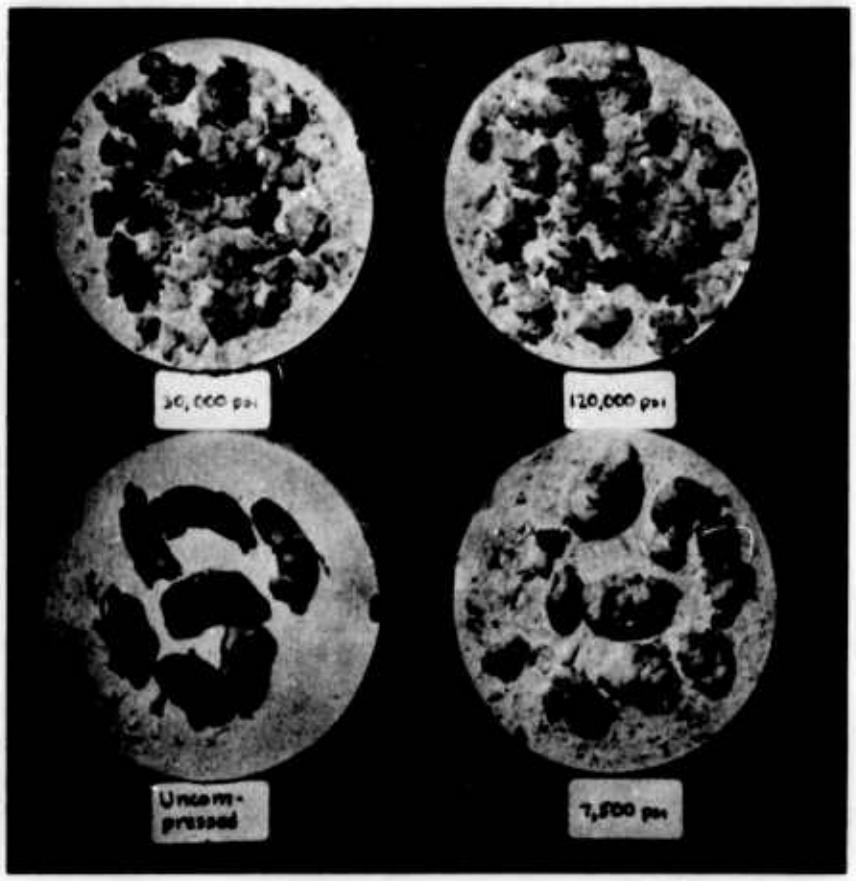


Figure 18 FRAGMENTATION OF SHRIMP

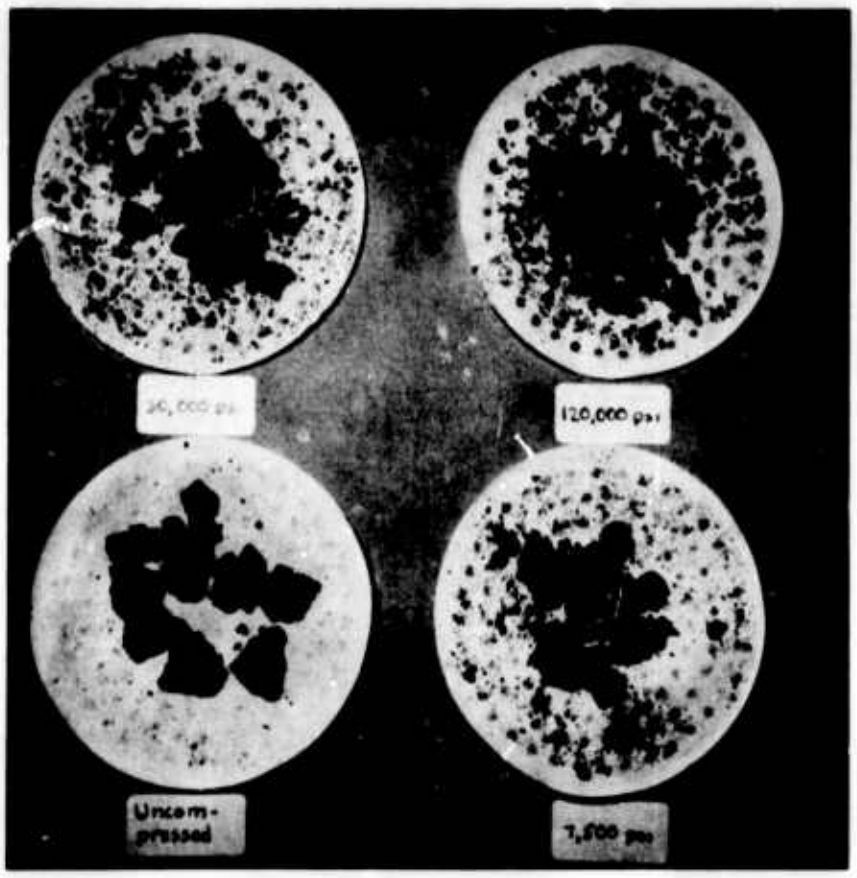
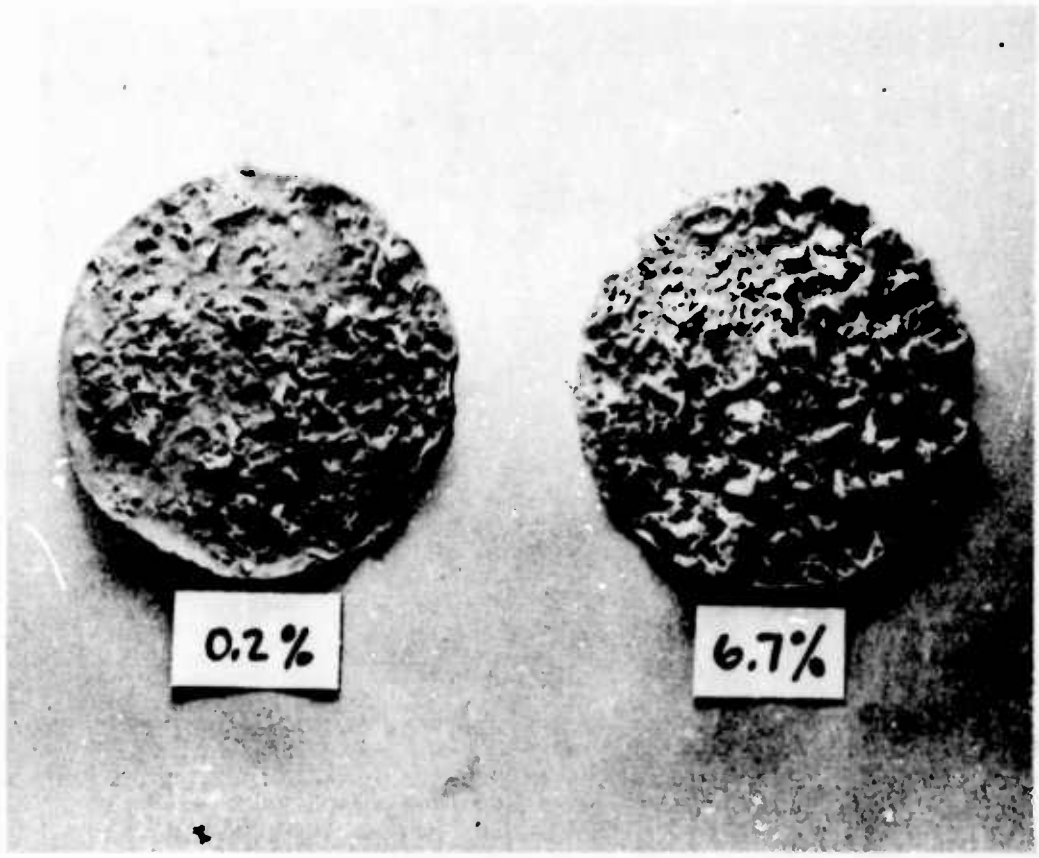
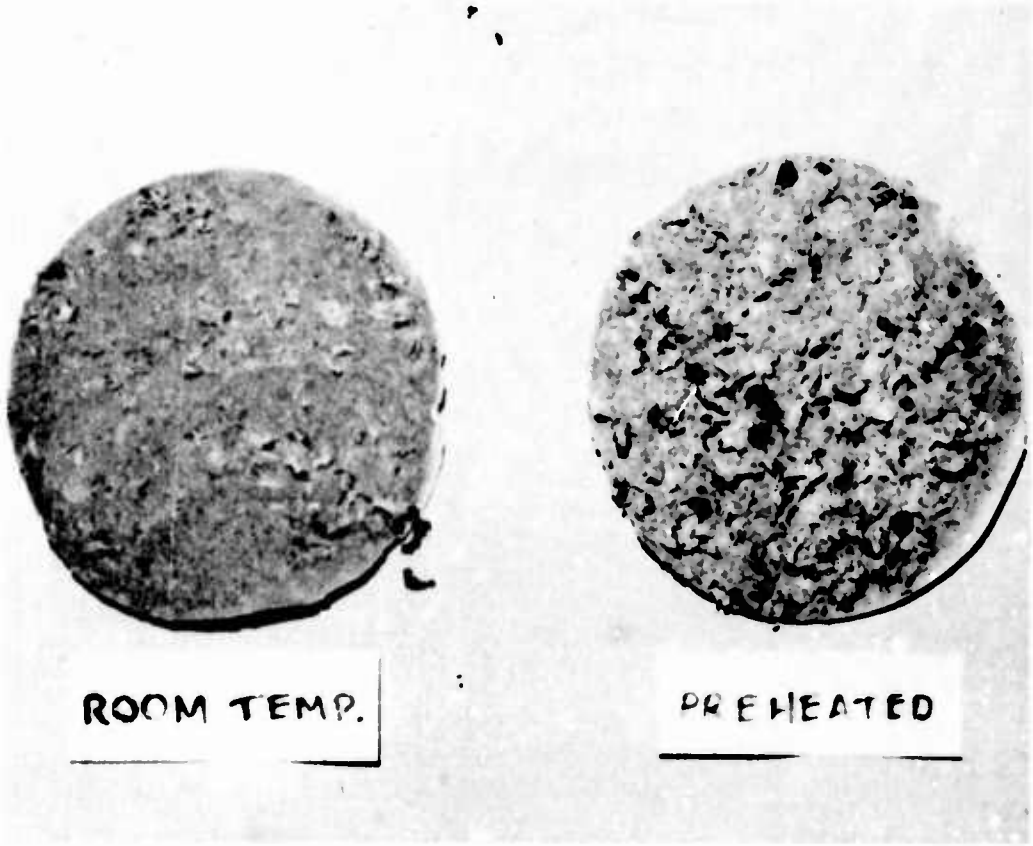


Figure 19 FRAGMENTATION OF RAW, FREEZE DRIED BEEF



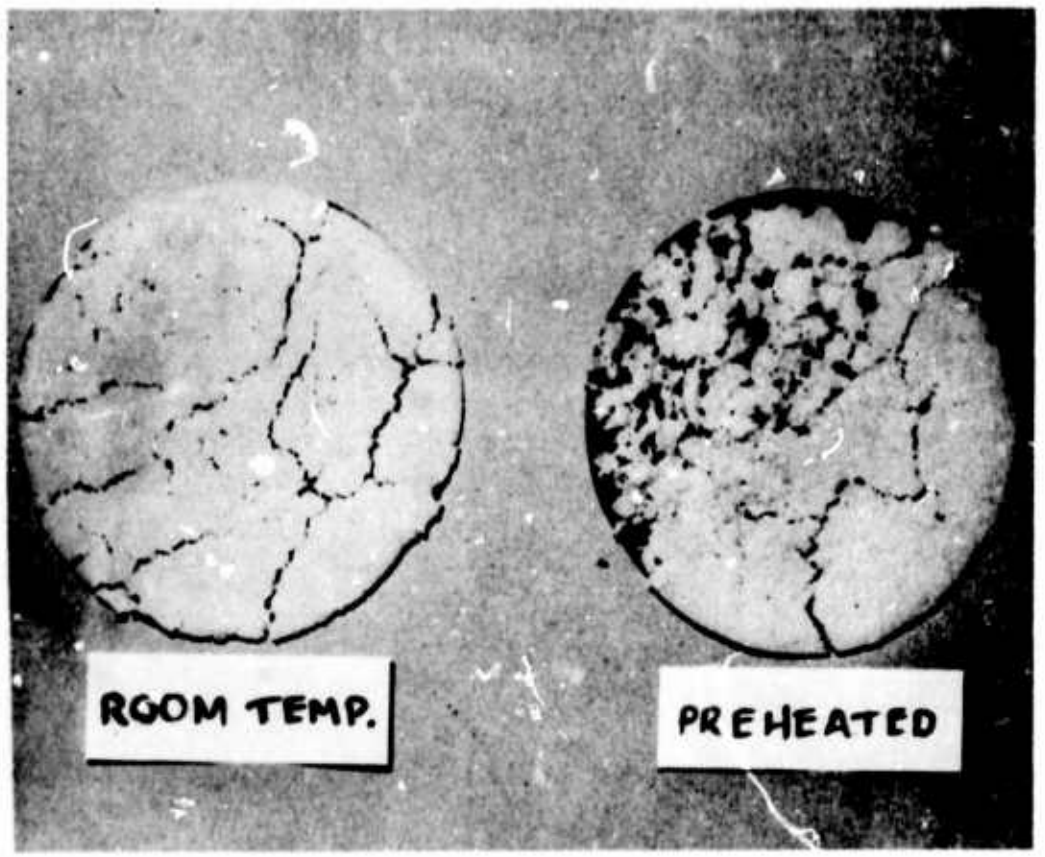
EFFECT OF MOISTURE LEVEL
ON FRAGMENTATION



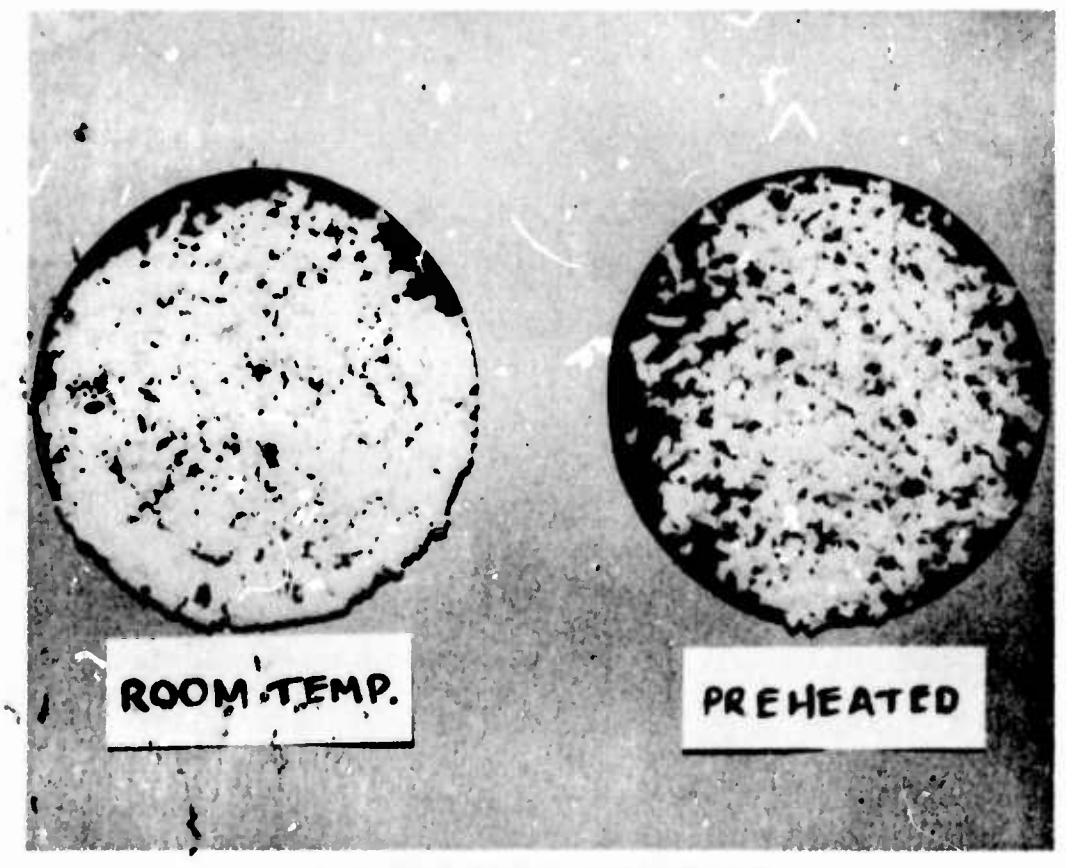
EFFECT OF ELEVATING THE OPERATING TEMPERATURES ON FRAGMENTATION
(0.2 PERCENT MOISTURE CONTENT)

PEAS COMPRESSED TO 120,000, 1/4" THICKNESS

Figure 20



1.2 PERCENT MOISTURE



9.4 PERCENT MOISTURE

EFFECT OF OPERATING TEMPERATURE AND MOISTURE ON FRAGMENTATION

(RICE COMPRESSED TO 120,000 PSI, 1/4" THICKNESS)

Figure 21

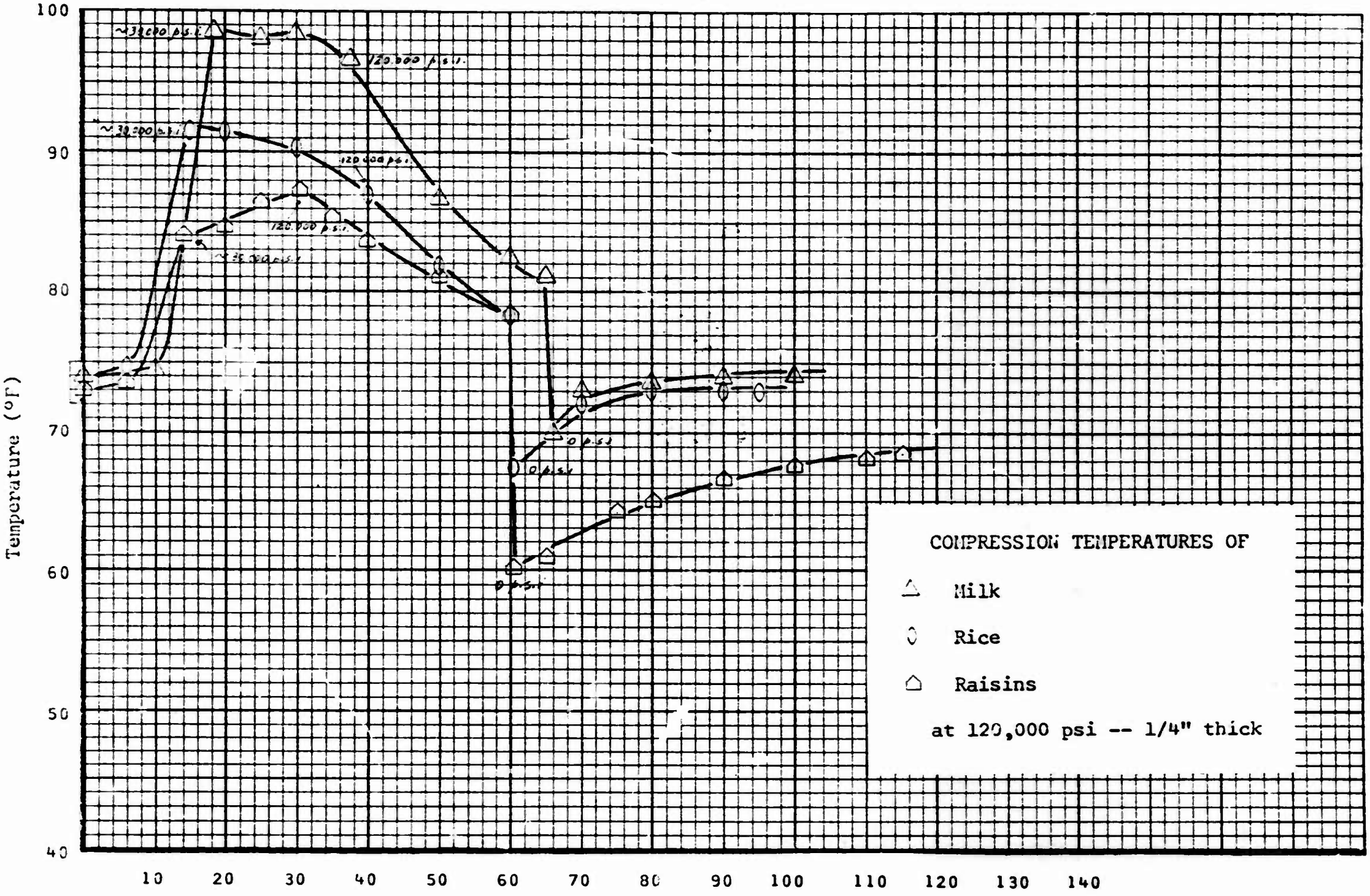

100
90
80
70
60
50
40
Temperature (°F)
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Pressure Time (seconds)
~32,000 p.s.i.
120,000 p.s.i.
~32,000 p.s.i.
120,000 p.s.i.
120,000 p.s.i.
~35,000 p.s.i.
0 p.s.i.
0 p.s.i.
0 p.s.i.
COMPRESSION TEMPERATURES OF
Milk
Rice
Raisins
at 120,000 psi -- 1/4" thick

FIGURE 22

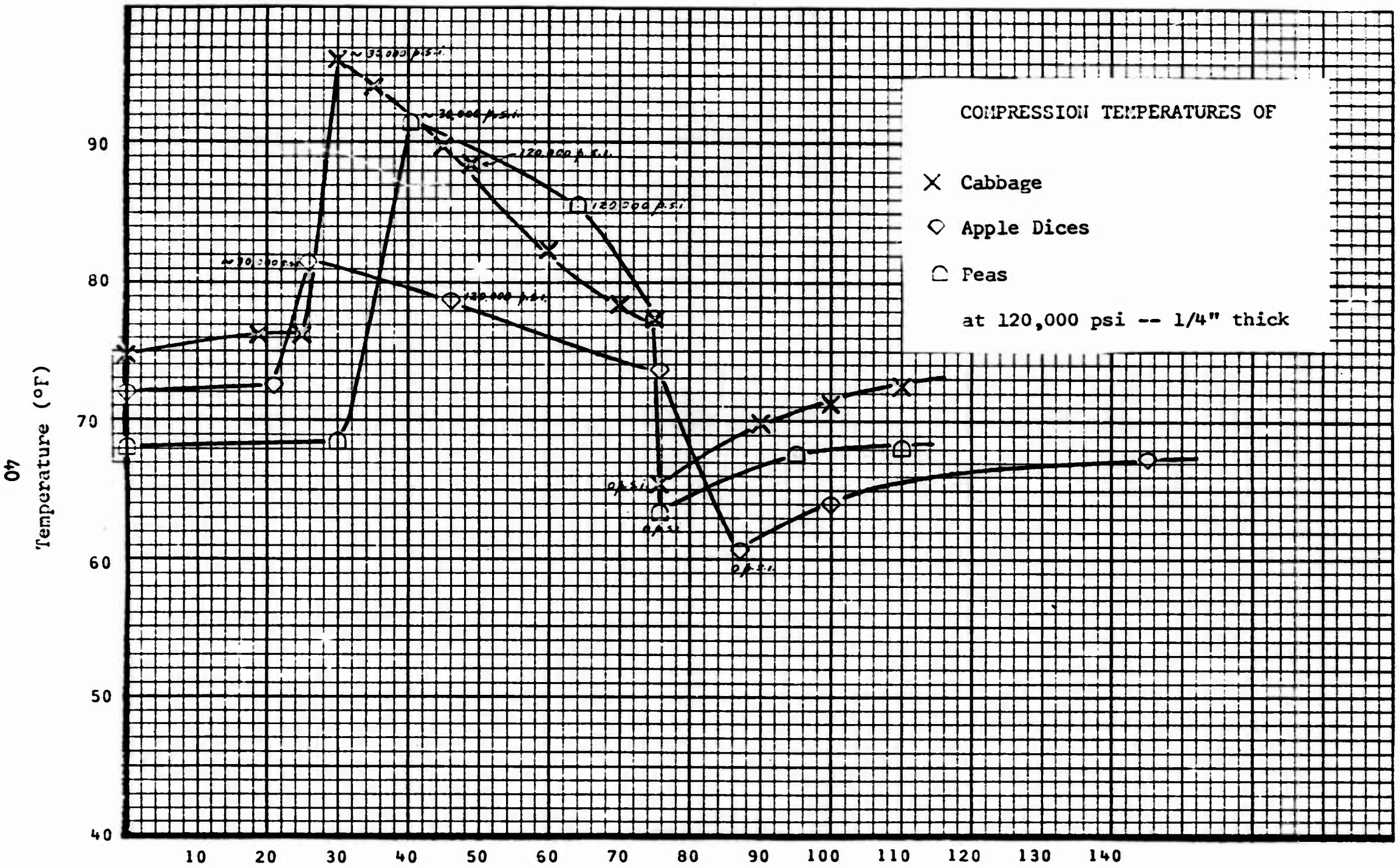

COMPRESSION TEMPERATURES OF
Cabbage
Apple Dices
Peas
at 120,000 psi -- 1/4" thick
Temperature (°F)
90
80
70
60
50
40
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Pressure Time (seconds)

FIGURE 23

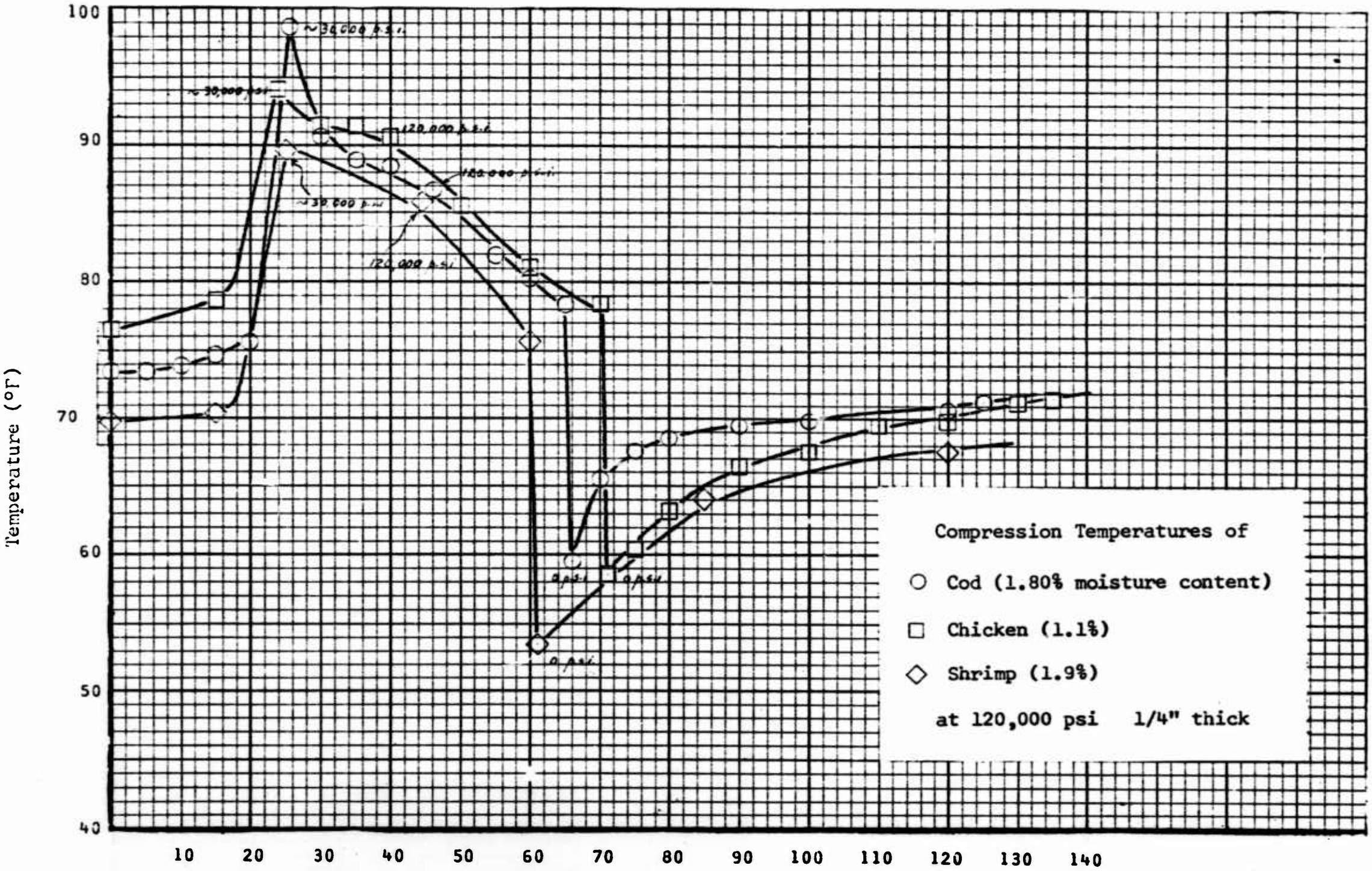

Temperature (°F)
100
90
80
70
60
50
40
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Pressure Time (seconds)
~30,000 p.s.i.
~30,000 p.s.i.
120,000 p.s.i.
~30,000 p.s.i.
120,000 p.s.i.
0 psi
0 psi
0 psi
Compression Temperatures of
Cod (1.80% moisture content)
Chicken (1.1%)
Shrimp (1.9%)
at 120,000 psi 1/4" thick

FIGURE 24

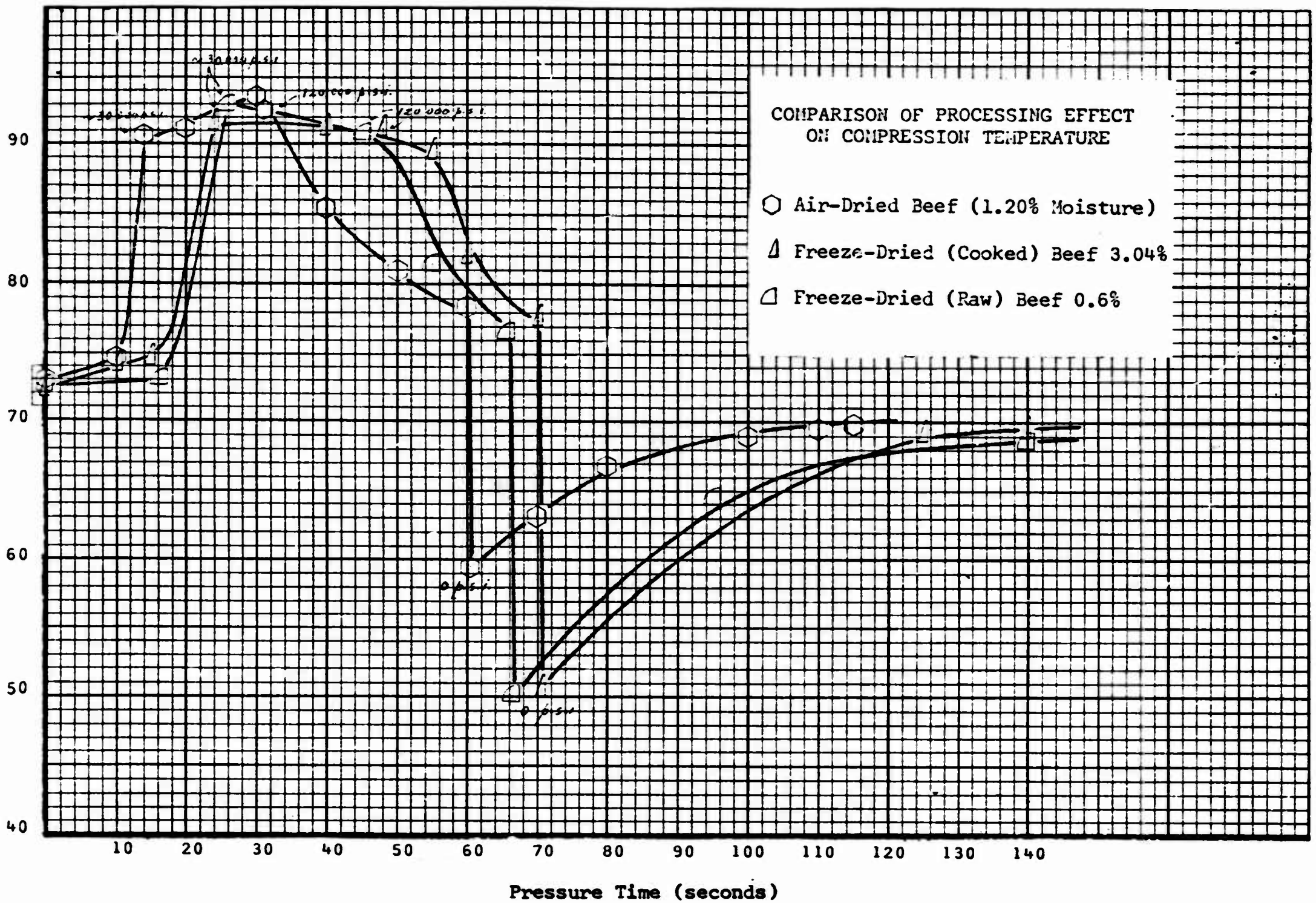

COMPARISON OF PROCESSING EFFECT
ON COMPRESSION TEMPERATURE
Air-Dried Beef (1.20% Moisture)
Freeze-Dried (Cooked) Beef 3.04%
Freeze-Dried (Raw) Beef 0.6%
Temperature (°F)
90
80
70
60
50
40
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Pressure Time (seconds)

FIGURE 25

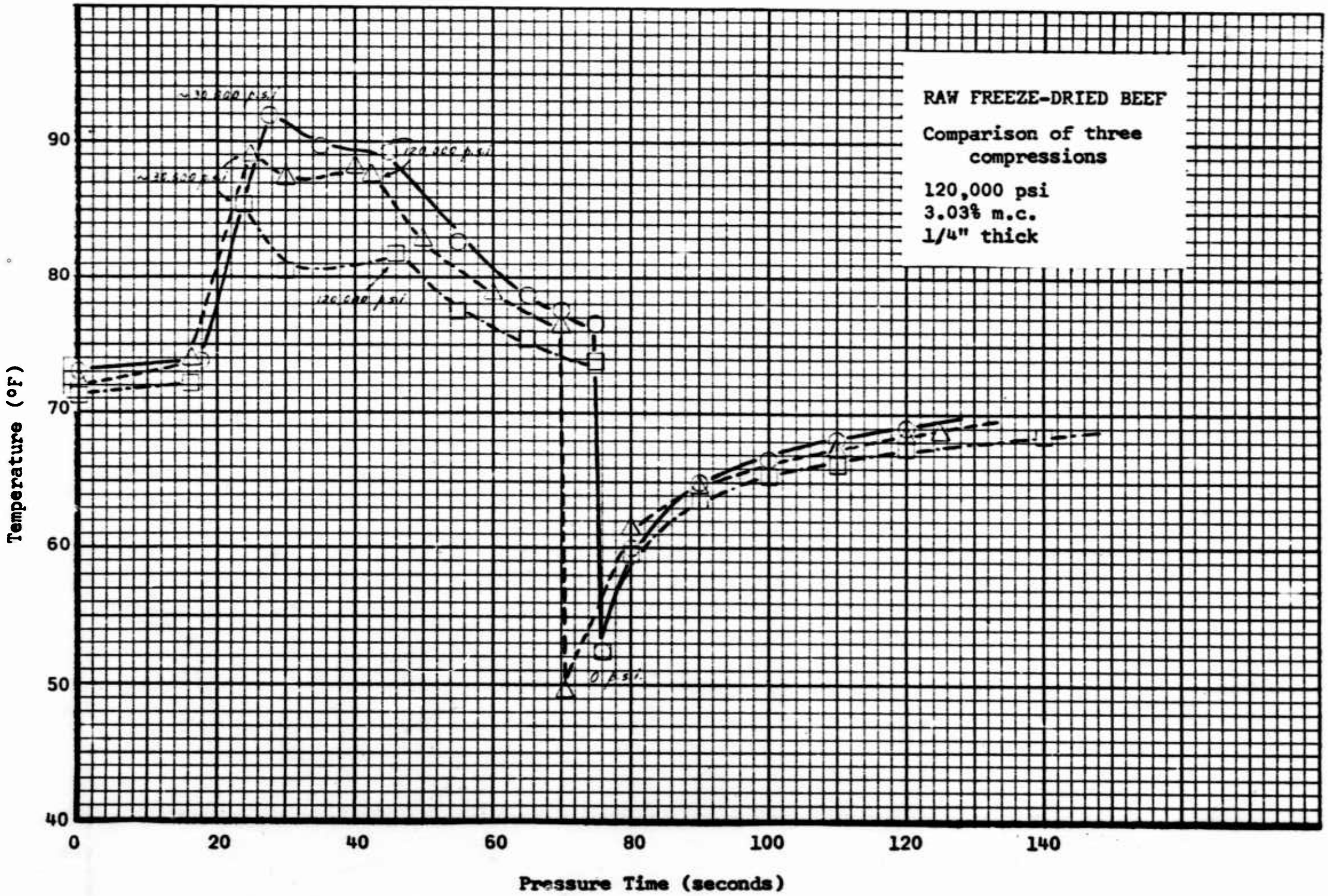

RAW FREEZE-DRIED BEEF
Comparison of three compressions
120,000 psi
3.03% m.c.
1/4" thick
~ 30,000 p.s.i.
~ 35,000 p.s.i.
120,000 p.s.i.
120,000 p.s.i.
0 p.s.i.
Temperature (°F)
90
80
70
60
50
40
0
20
40
60
80
100
120
140
Pressure Time (seconds)

FIGURE 26

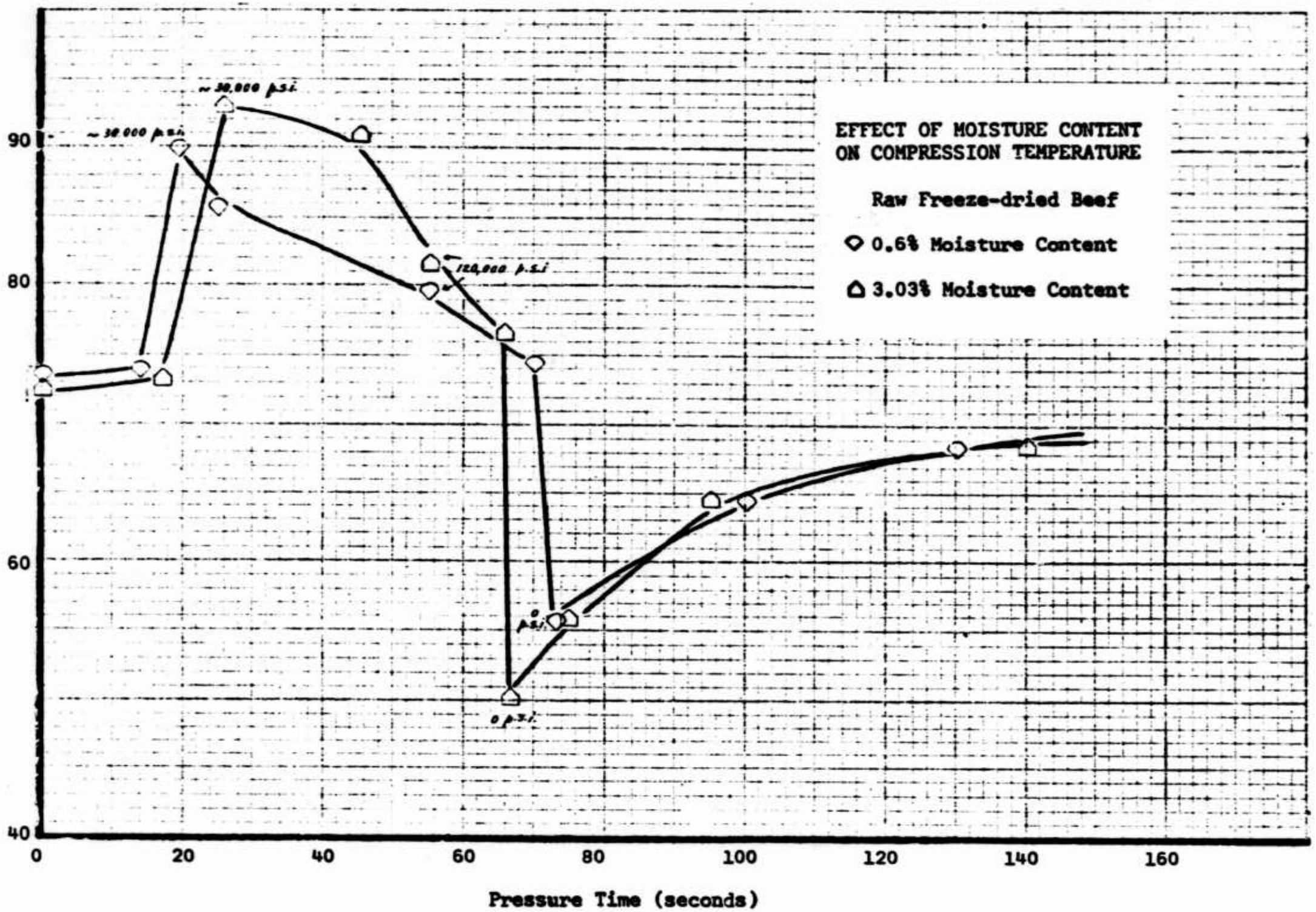

EFFECT OF MOISTURE CONTENT
ON COMPRESSION TEMPERATURE
Raw Freeze-dried Beef
◇ 0.6% Moisture Content
△ 3.03% Moisture Content
~30,000 p.s.i.
~30,000 p.s.i.
120,000 p.s.i.
0 p.s.i.
90
80
60
40
0
20
40
60
80
100
120
140
160
Temperature (°F)
Pressure Time (seconds)

FIGURE 27

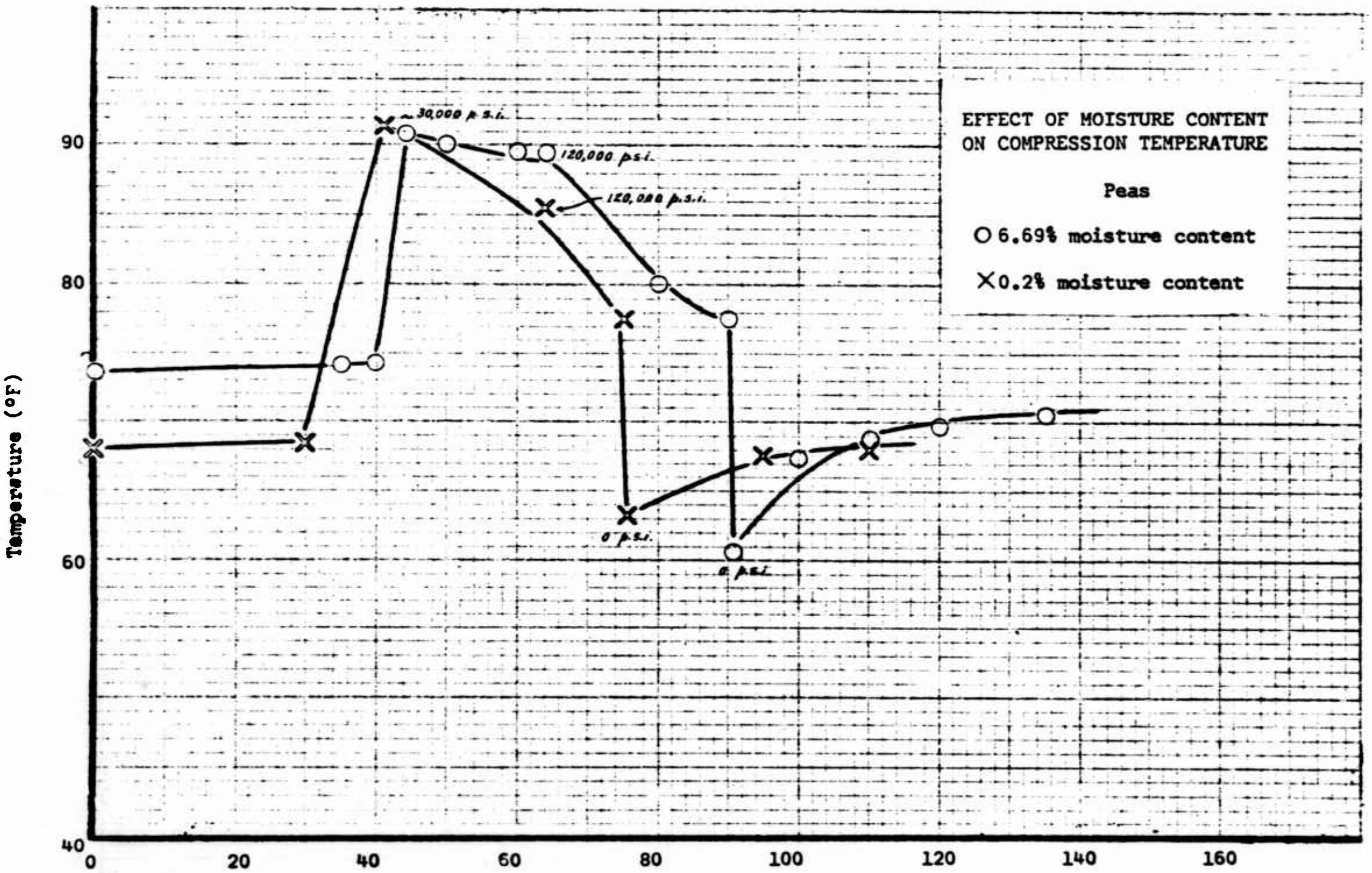

EFFECT OF MOISTURE CONTENT
ON COMPRESSION TEMPERATURE
Peas
O 6.69% moisture content
X 0.2% moisture content
30,000 p.s.i.
120,000 p.s.i.
120,000 p.s.i.
0 p.s.i.
0 p.s.i.
Temperature (oF)
90
80
60
40
0
20
40
60
80
100
120
140
160
Pressure Time (seconds)

FIGURE 28

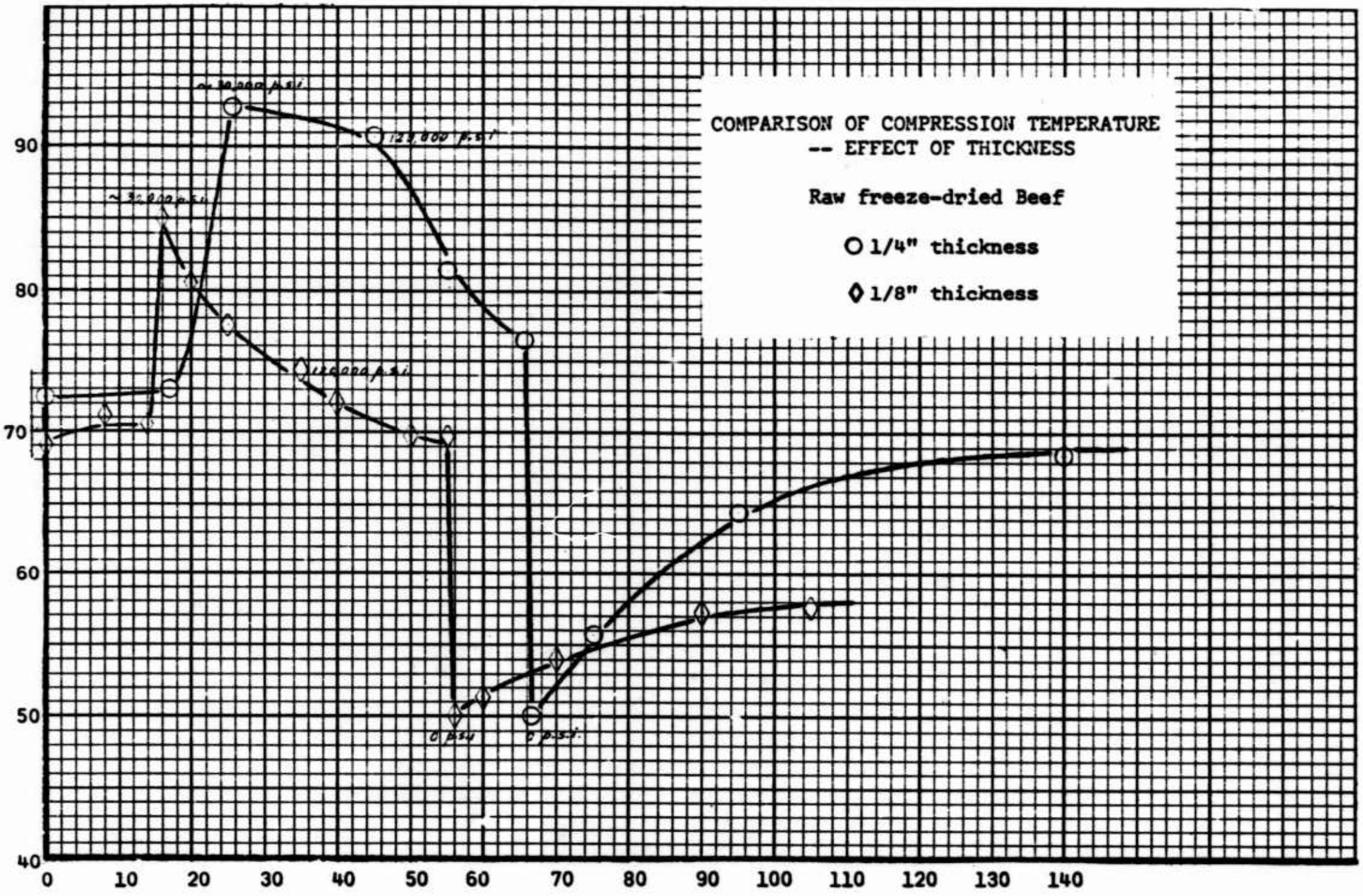

COMPARISON OF COMPRESSION TEMPERATURE
-- EFFECT OF THICKNESS
Raw freeze-dried Beef
○ 1/4" thickness
◊ 1/8" thickness
~ 30,000 p.s.i.
12,000 p.s.i.
~ 30,000 p.s.i.
12,000 p.s.i.
0 p.s.i.
0 p.s.i.
Temperature (°F)
90
80
70
60
50
40
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Pressure Time (seconds)

FIGURE 29

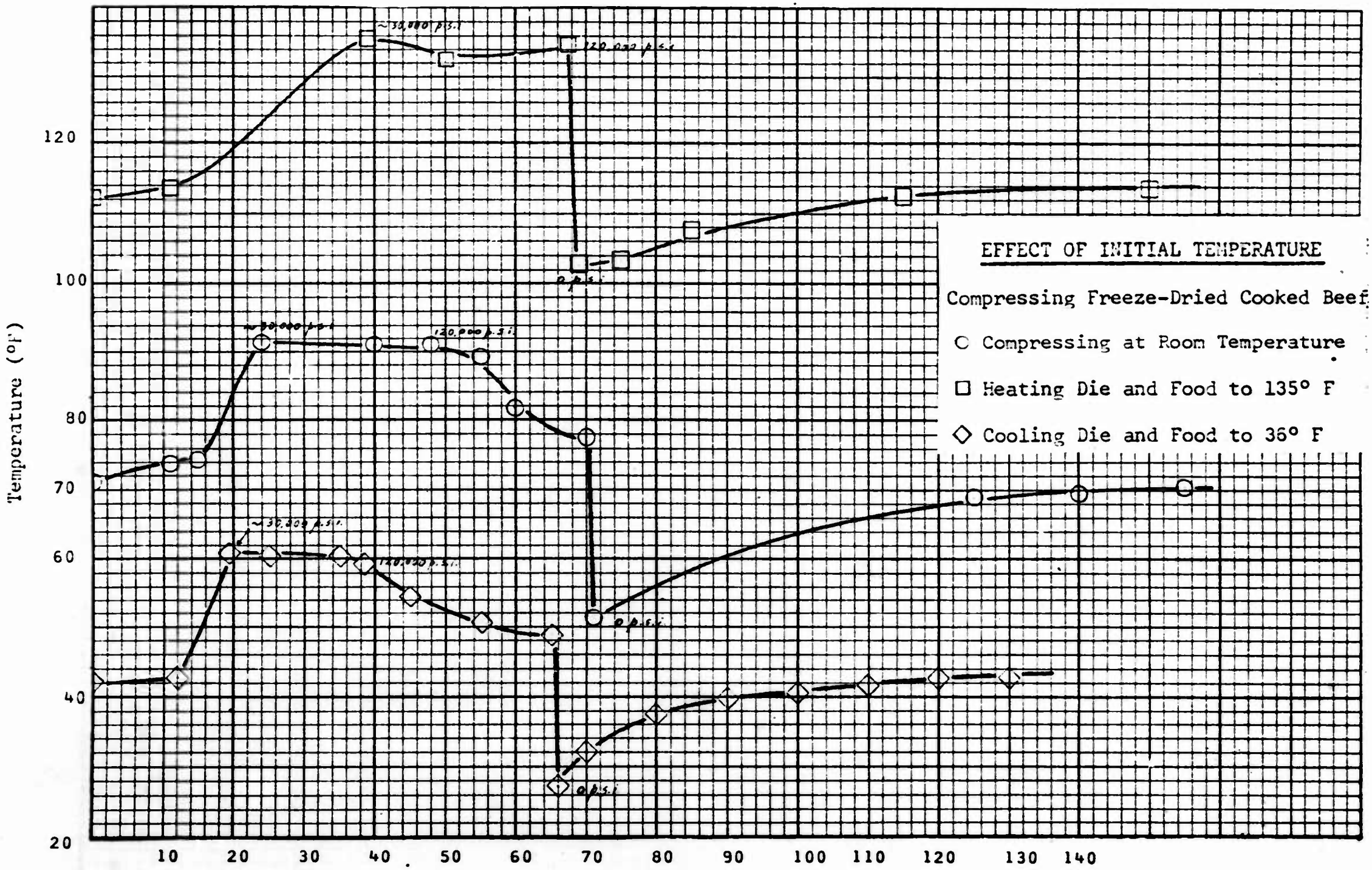

~35,000 p.s.i.
120,000 p.s.i.
0 p.s.i.
~30,000 p.s.i.
120,000 p.s.i.
0 p.s.i.
~35,000 p.s.i.
120,000 p.s.i.
0 p.s.i.
EFFECT OF INITIAL TEMPERATURE
Compressing Freeze-Dried Cooked Beef
○ Compressing at Room Temperature
□ Heating Die and Food to 135° F
◇ Cooling Die and Food to 36° F
Temperature (°F)
120
100
80
70
60
40
20
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Pressure Time (seconds)

FIGURE 30

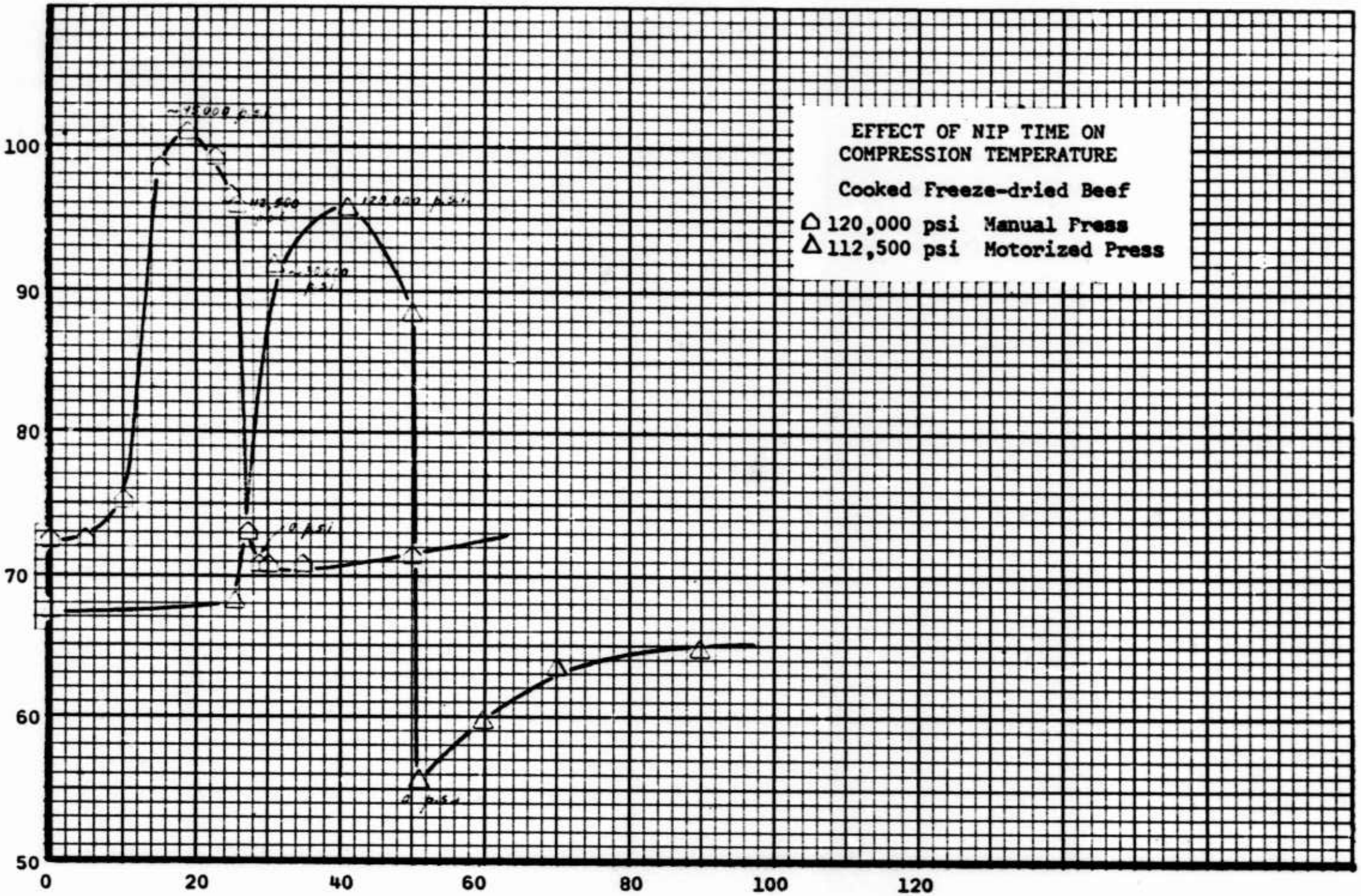

EFFECT OF NIP TIME ON
COMPRESSION TEMPERATURE
Cooked Freeze-dried Beef
△ 120,000 psi Manual Press
△ 112,500 psi Motorized Press
Temperature (°F)
100
90
80
70
60
50
0
20
40
60
80
100
120
Pressure Time (seconds)

FIGURE 31

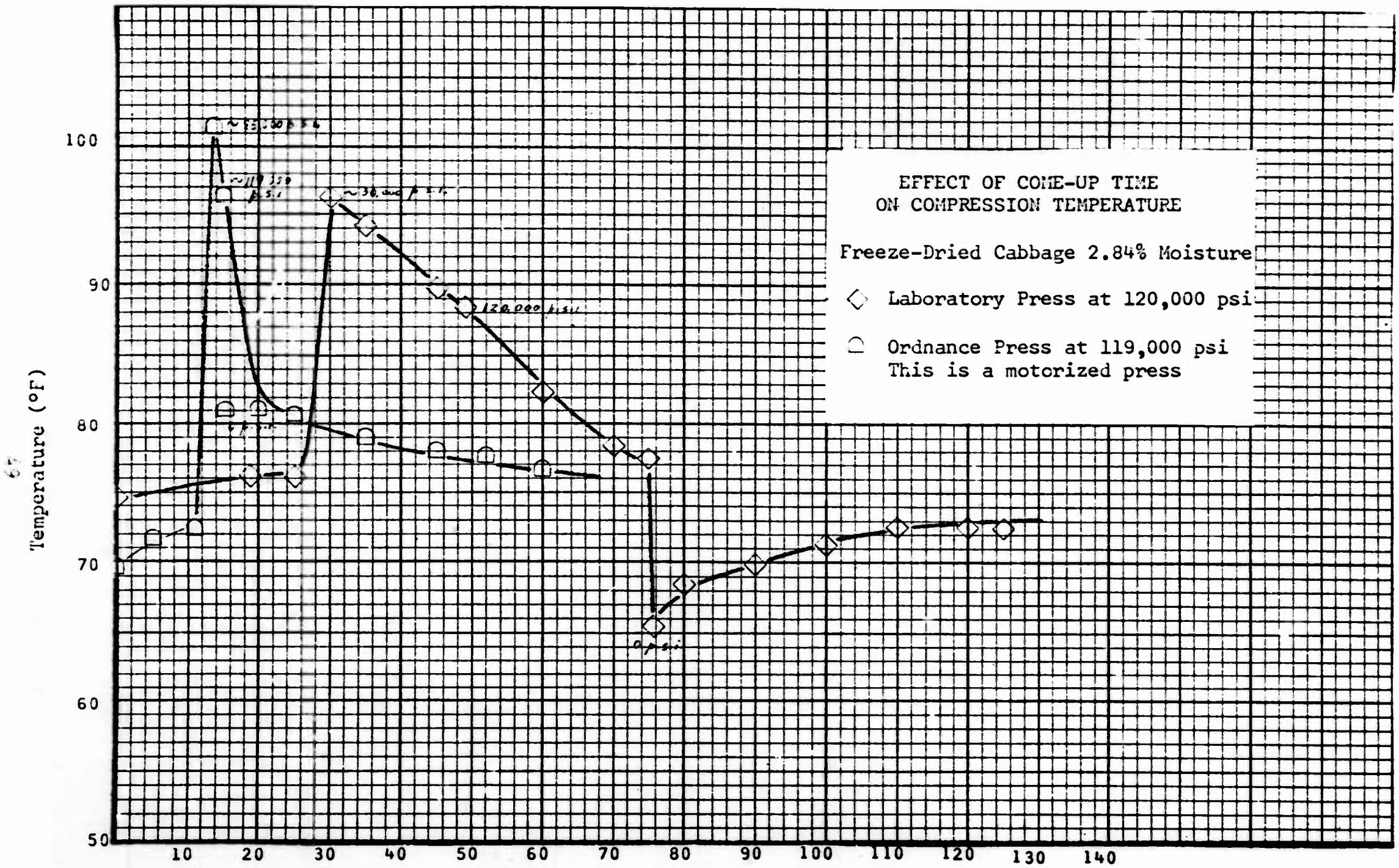

EFFECT OF COME-UP TIME
ON COMPRESSION TEMPERATURE
Freeze-Dried Cabbage 2.84% Moisture
Laboratory Press at 120,000 psi
Ordnance Press at 119,000 psi
This is a motorized press
Temperature (°F)
100
90
80
70
60
50
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Pressure Time (seconds)

FIGURE 32

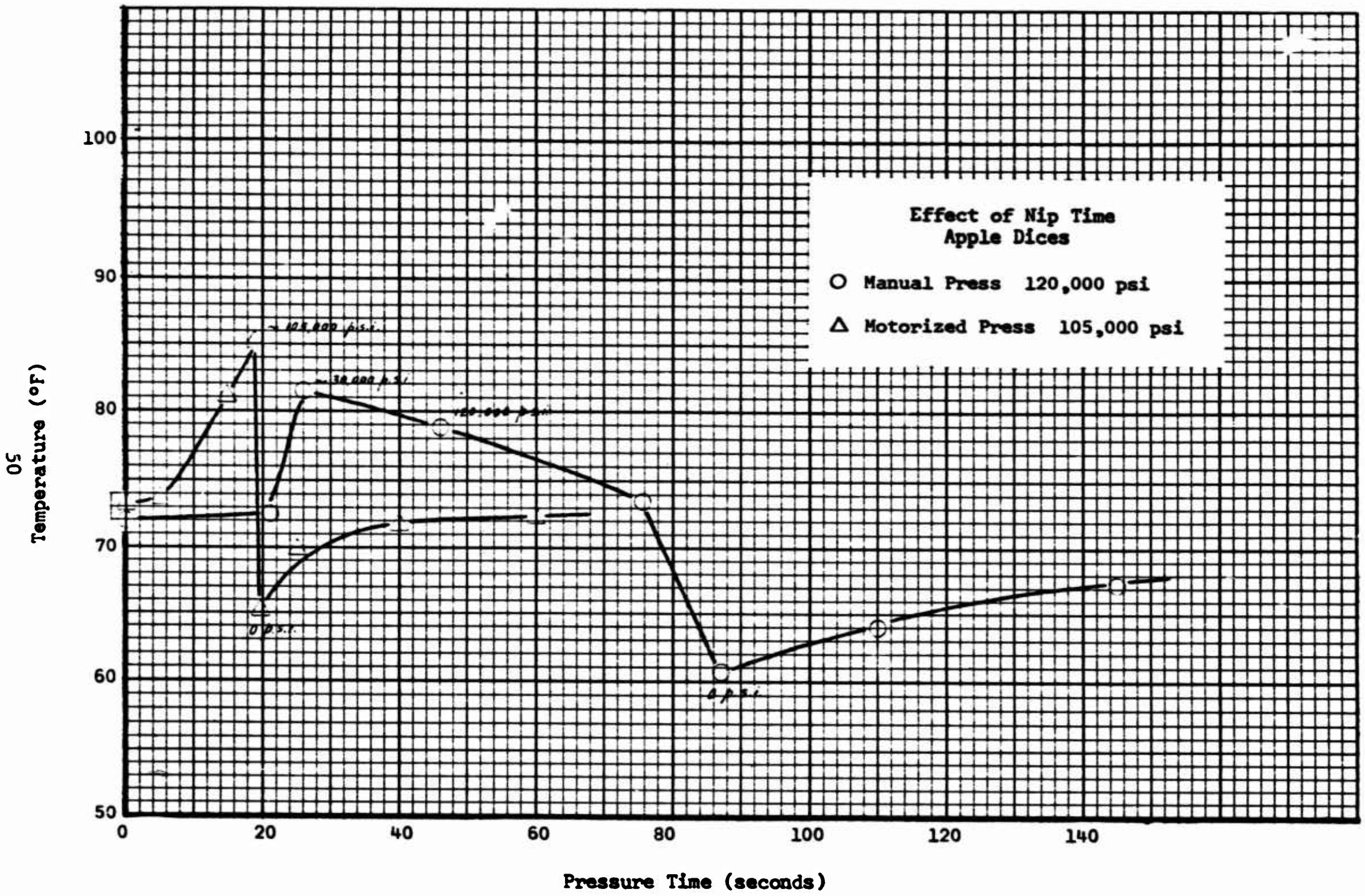

Effect of Nip Time
Apple Dices
O Manual Press 120,000 psi
Δ Motorized Press 105,000 psi
105,000 p.s.i.
30,000 p.s.i.
120,000 p.s.i.
0 p.s.i.
0 p.s.i.
Temperature (°F.)
100
90
80
70
60
50
0
20
40
60
80
100
120
140
Pressure Time (seconds)

FIGURE 33

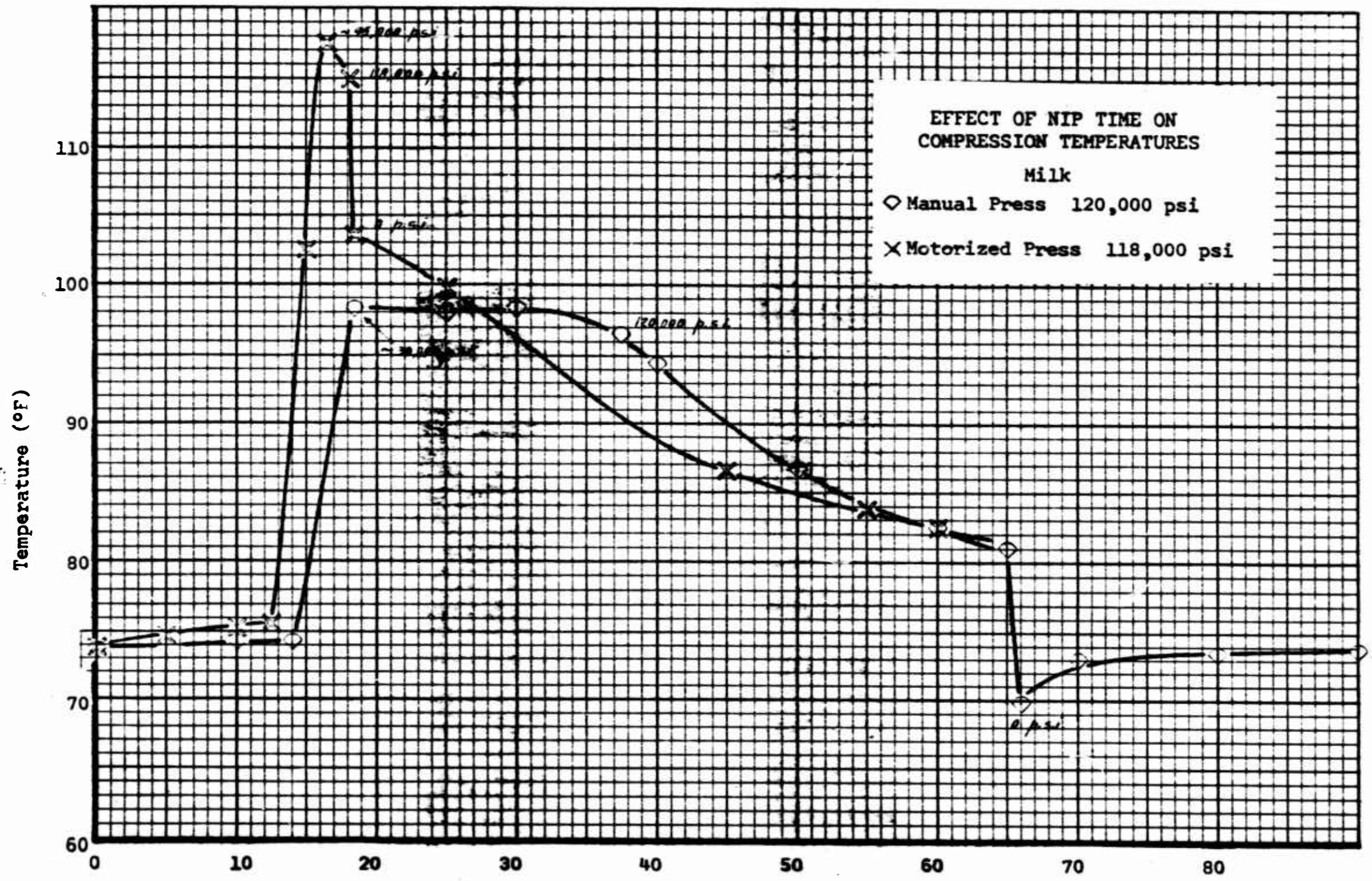

EFFECT OF NIP TIME ON
COMPRESSION TEMPERATURES
Milk
◇ Manual Press 120,000 psi
× Motorized Press 118,000 psi
Temperature (°F)
110
100
90
80
70
60
0
10
20
30
40
50
60
70
80
Pressure Time (seconds)

FIGURE 34

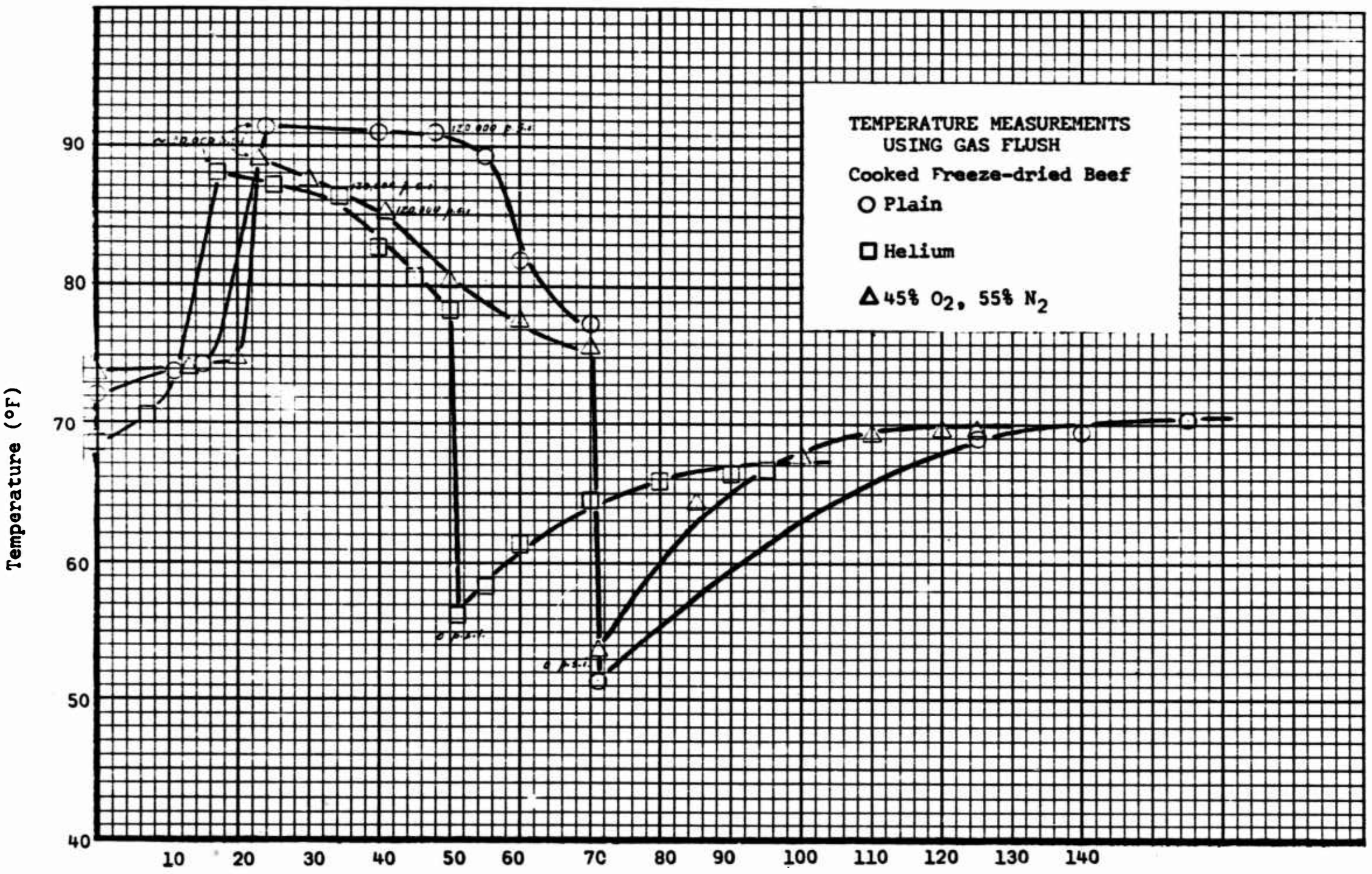

TEMPERATURE MEASUREMENTS
USING GAS FLUSH
Cooked Freeze-dried Beef
O Plain
□ Helium
△ 45% O_2, 55% N_2
Temperature (°F)
90
80
70
60
50
40
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Pressure Time (seconds)

FIGURE 35

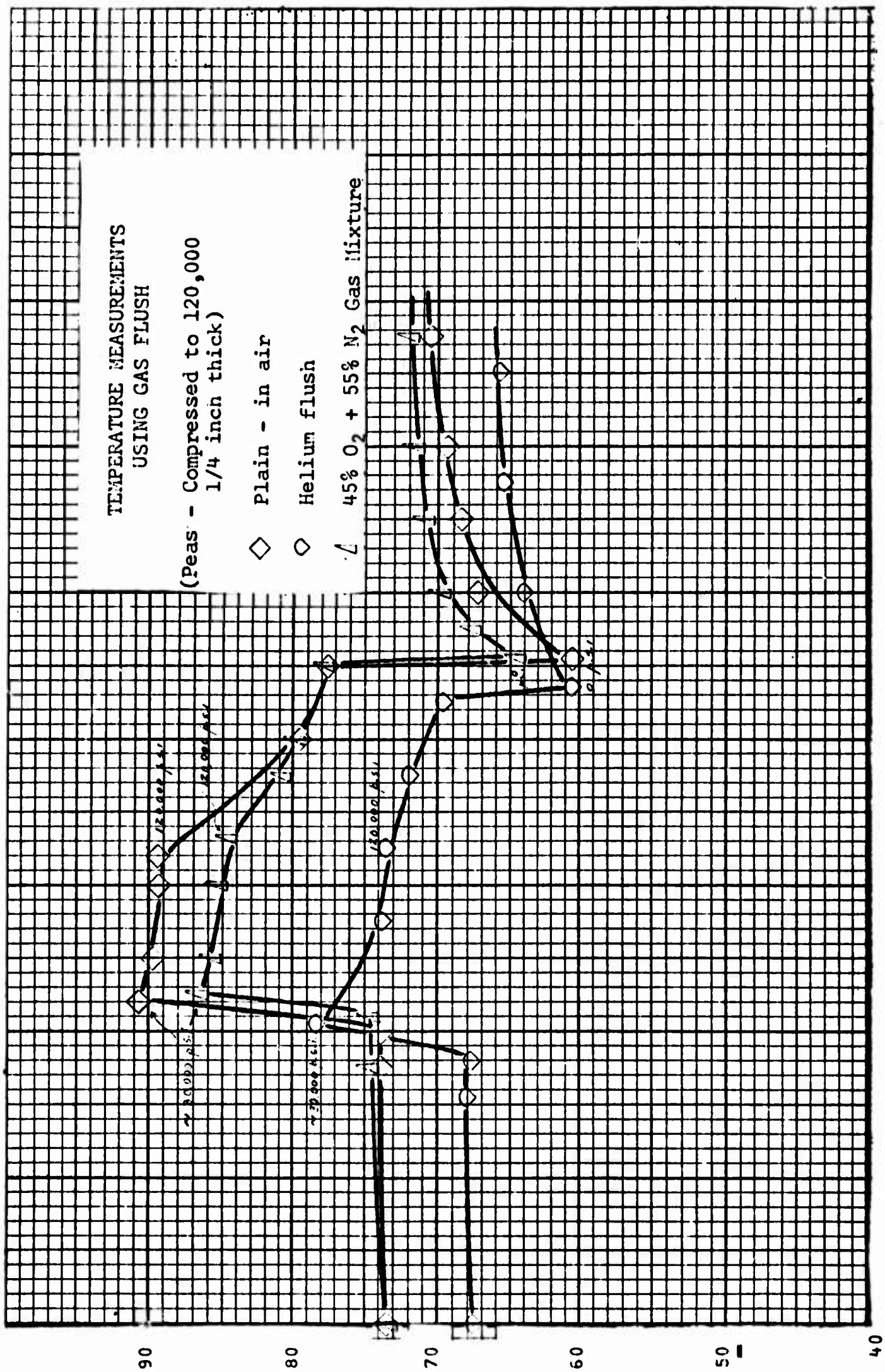

TEMPERATURE MEASUREMENTS
USING GAS FLUSH
(Peas - Compressed to 120,000
1/4 inch thick)
◇ Plain - in air
◇ Helium flush
45% O_2 + 55% N_2 Gas Mixture
Temperature (°F)
90
80
70
60
50
40
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Pressure Time (seconds)

FIGURE 36

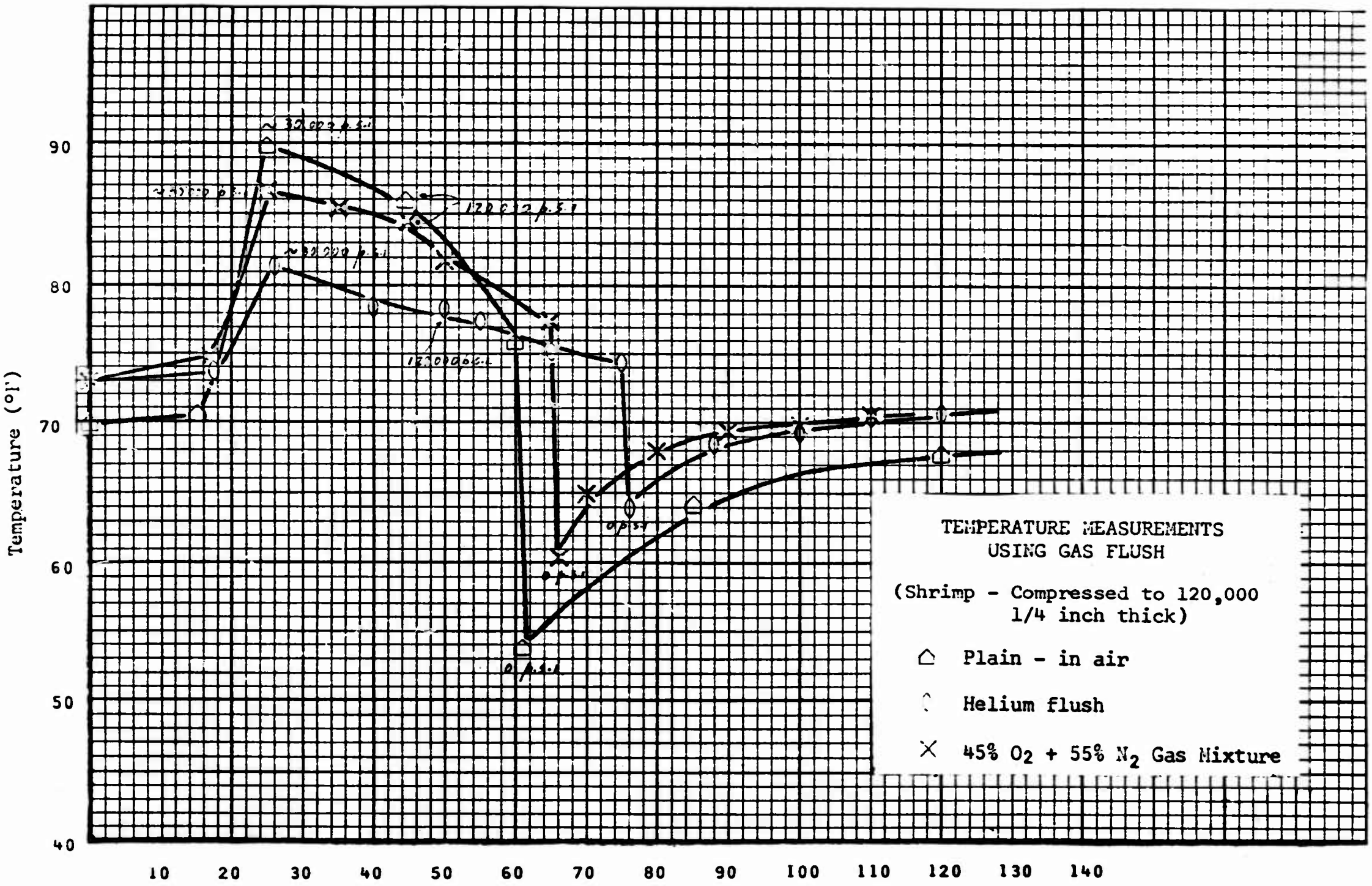

90
80
70
60
50
40
Temperature (°F)
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Pressure Time (seconds)
TEMPERATURE MEASUREMENTS
USING GAS FLUSH
(Shrimp - Compressed to 120,000
1/4 inch thick)
Plain - in air
Helium flush
45% O_2 + 55% N_2 Gas Mixture

FIGURE 37

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*
Central Engineering Laboratories
FMC Corporation
Santa, Clara, California

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP

3. REPORT TITLE

ULTRA-HIGH COMPRESSION OF DRIED FOODS

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Final: 20 April 1964

5. AUTHOR(S) *(Last name, first name, initial)*

Lampi, R. A., Takahashi, H., Battey, R. F., Lennon, J., Sierra, S.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
November 1965	54	5

8a. CONTRACT OR GRANT NO.
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b. PROJECT NO.
7X84-06-033

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
FD-35

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11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
Food Division, U. S. Army Natick Laboratories, Natick, Mass. 01762

13. ABSTRACT

This report covers the study of the effects of pressures as high as 120,000 psi on various dried foods. High compression did not produce any detectable chemical changes. Compressed foods became difficult to rehydrate and exhibited considerable fragmentation when hydrated. Temperature changes occuring during high compression operations were studied. The equipment used for achieving high pressures and the construction of the die are discussed.

DD FORM 1 JAN 64 1473

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Compression	8		6		4	
Dehydrated foods	1		7		4	
Pressure			6		4	
High	0		0		0	
Temperature			7			
Military rations	4		4			
Sorption			7			
Taste			7			
Fragmentation			7			
Design					8	
Dies					9	

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